LANDFILL CONTAINMENT AND WASTE MANAGEMENT SYSTEMS

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The opinions and observations expressed in this thesis are those of the author and are not necessarily those of Ove Arup & Partners or Parsons Brinckerhoff - Built Environment Division.

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ABSTRACT

This thesis report addresses the role of landfill disposal within the framework of the modern Integrated Solid Waste Management (ISWM) hierarchy.

The aims of the research are presented in the context of a literature search and postal questionnaire survey to identify trends in United Kingdom landfill containment concepts. These are compared and contrasted with the approaches of other countries to landfill containment design and set against the background of pre-treatment and recovery processes aimed at minimising the volume of wastes for disposal.

To introduce the subject the production of waste, waste compositions and waste quantities are explained. The philosophy of integrated solid waste management is presented together with the continuing role of landfill disposal within the ISWM hierarchy.

Explanations of the processes of waste decomposition are set out with an indication of the environmental concerns associated with landfill leachate and landfill gas. The principles of containment engineering are introduced, set against the evolutionary design history of landfill engineering in the United Kingdom.

The modern design and construction processes now considered best practice in the United Kingdom are explained, including the concepts of Risk Assessment and Construction Quality Assurance (CQA). A comparison of the design and construction standards adopted in other countries is presented and this is contrasted with the UK approach.

Results of a postal questionnaire of UK landfills are presented with respect to general site details, engineering philosophy, pollution control methods and future policy initiatives. The findings are compared to the United Kingdom and European Union policies of the mid to late 1990s which presented the differing strategies of "bio-reactor landfill" against waste pretreatment and residue disposal respectively.

Finally the main findings of the study exercise are presented and discussed. Summary thoughts and observations are offered and areas of further study and continuing research in this field are suggested.

CONTENTS

1. CHAPTER 1 - INTRODUCTION

1.1. Background

Landfill engineering has attracted increasing public interest in recent years as concern over the protection of the environment has grown. The use of heavily engineered landfill containment systems has become common in the United States and Germany, not only for hazardous wastes, but also with increasing regularity for domestic wastes.

The use of synthetic geomembranes in combination with low permeability mineral liners is a common solution for basal containment systems particularly where the risk to groundwater regimes is considered high (Potter, H.A.B. & Yong, R.N. (1995), Seymour, K.J. & Street, A. (1995)). The incorporation of synthetic geomembranes in the Final Cover or Capping Layers of landfills is now also being actively encouraged by many Waste Regulatory Authorities - the aim being to encapsulate the waste hence controlling leachate production and so providing further protection of the Environment (Forster, A.M. (1)(1995), Forster, A.M. (2)(1995), Wallis, M.K. (1995)).

With encapsulation comes control over the leachate production and landfill gas generation arising from the decomposition processes. The rate of decomposition is obviously of great importance and much debate is currently centred on the merits of "dry cell" decomposition where water is excluded or "wet cell" decomposition where the percolation of water through the waste mass is actively encouraged (Uehling, M. (1993)). In the latter scenario a system of perforated horizontal and vertical pipes can be installed to accomplish the recirculation of leachate fluids. The recirculated fluid allows micro-organisms to thrive and this promotes the processes of chemical and biological reduction. The rate of chemical and biological reduction is directly linked to the speed at which the restored landfill surface can be expected to settle. Knowledge and control of the rate of decomposition and deformation is obviously an advantage when designing and phasing final cover systems (Sanches-Alciturri, J.M., et al (1995)).

Current legislative direction is to encapsulate the wastes in a "dry cell" with final cover systems being implemented soon after the final waste profile has been reached. This approach may be flawed as isolation of the wastes in the "dry" environment can lead to higher concentrations of toxins as they do not benefit from the regular flushing process as in "wet cells" where leachates are recirculated (De Silva, M.S., et al (1995)). Premature placement of the final cover system may also lead to future failure due to the large differential settlements which can take place.

Alternative options for the installation and phasing of landfill cover systems indicate that a two stage cover process is likely to lead to better long term results (Daniel, D.E. (1995)). In this system an intermediate or temporary cover system is first put in place. This can be combined with leachate recirculation with the aim of accelerating decomposition and settlement processes.

In placing temporary and permanent final cover systems careful selection of natural and synthetic capping materials is essential (Hoekstra, S.E. (1995), Beine, R.A., Dahlman, K. (1995)). Historically clays have been used extensively in capping applications, primarily due to their general availability at some landfill sites but also due to their low permeability when properly compacted in layers. An inherent disadvantage of clay covers is their limited ability to accommodate large differential settlements. This has been successfully overcome at some landfill sites by combining the clay cover with a synthetic geomembrane cap. A favoured synthetic membrane has been High Density Polyethylene (HDPE) but current trends favour the use of Very Low Density Polyethylene due to improved elongation properties and its ability to mould itself to the settlement profile of the landfill. Commercial products, known as Geocomposite Clay Liners (GCLs), are now also available and these combine geotextiles with the self healing mineral Bentonite. Whereas geomembranes require welded seams to ensure their integrity the geocomposites can be placed in lapped "roof tile" fashion with the Bentonite providing an efficient seal. The merit of welding the pure geosynthetic may also be questioned, however, particularly if the landfill facility is to operate on the "wet cell" principle.

In the absence of suitable clay covers certain "low grade" or "secondary" waste

materials have been used successfully, sometimes on their own, but also in combination with geomembranes. These materials include colliery shale, pulverised fuel ash, gravel washery silts, etc. The permeabilities of these materials, whilst not all achieving the values of natural clays, have been tested as having a permeability classification of "low" to "very low". This has been encouraging and further successful trials in the United States have also identified waste paper pulp as an effective "impermeable" cover material (Zimmie T.F., et al (1995)).

Naturally occurring soils other than clays have also been successfully used in combination with Bentonite. This process of Bentonite Soil (and Sand) Enrichment has been successful in providing soil covers and liners of the desired permeability where natural clay materials have been unavailable.

It can be seen that a variety of lining and capping options is available. Knowledge of the frequency of use and success of these cover designs would be beneficial to engineers when considering cover systems for new sites. Also important is the context within which landfill disposal will continue to be viewed as part of an overall Integrated Solid Waste Management Programme. It is likely that processes such as waste incineration, composting and digestion (with linked energy recovery), combined with initiatives on waste minimisation, recycling and reuse will alleviate the UK's reliance on landfilling. From the aforementioned processes the performance of the resulting residues destined for landfill will be more predictable reducing the range of stresses and strains to which linings and cappings are currently subjected. Landfill designs will become more reliable and this will be combined with the more benign character of the pre-treatment residues being buried. Overall the hazard posed to the environment from landfills will be much reduced as the leachate and gas production within the buried mass will effectively be eliminated.

1.2. Research Aims

The aims of this research study are as follows:

- Define the current levels of waste production.

- Present the principles of modern ISWM systems.
- Define the current role of landfill disposal.
- Identify landfilled waste decomposition processes.
- Identify major environmental concerns.
- Set out the principles of landfill containment systems.
- Identify International variations in landfill designs.
- Survey UK (England & Wales) Landfill/ISWM Practice.
- Review survey returns and comment on findings.
- Reassess ISWM trends and the future role of landfill.
- Summarise and discuss study findings.
- Recommend further areas of study.

Methodologies employed in achieving the study aims have included:

- Survey by Postal Questionnaire.
- Literature Search (references are listed at the end of the document).

1.3. Report Structure

Reporting of this research project and the achievement, or otherwise, of the study aims, is set out in chapter format as follows:

Chapter1: In this Chapter 1 the study topic is introduced and the study aims defined. The structure of the study thesis is set out.

Chapter 2: Chapter 2 explains the composition and scale of waste production in developed western economies with a comparison against less developed countries. The need for efficient waste management systems combined with economic and safe final disposal strategies is explained.

The elements making up the modern waste management hierarchy are explored and the interaction and interdependency of these elements is examined. The roles of waste minimisation, recycling/reuse, waste transformation and waste disposal are

reviewed. Typical processes are identified.

Within the waste management hierarchy the reliance on landfill disposal is examined. The current level of dependency is assessed with commentary provided on likely changes in the level of importance assigned to landfilling as alternative waste transformation and recycling/reuse technologies are brought to the market in greater volume.

Chapter 3: The main physical, chemical and biological processes acting within a landfill waste mass are assessed, together with the harmful leachate and landfill gas by-products produced.

An examination of the environmental impacts and harm arising from the release of leachates and gases from landfills is presented. Major concerns, including the damage to groundwater resources and the atmosphere, are examined, plus the potential impacts on animal life and human health.

The main components of a waste landfill's environmental control systems are examined. Elements considered include containment by basal lining systems and capping and cover layers. Leachates and landfill gas management systems are reviewed in combination with the containment techniques which act as the prime protectors of the natural environment. The concepts of "dry cell" and wet bio-reactor technologies are presented.

The chapter concludes with a brief history of landfill design within the United Kingdom. The development of landfills in the UK within old mineral workings is recognised together with the move forward to conscious design firstly in the form of "dilute and disperse" concepts and most recently the adoption of "containment" techniques.

Chapter 4: Following on from the brief history of UK landfill design described in Chapter 3, the latest UK Best Practice on Landfill design is set out in this chapter. Focusing on containment the chapter describes liner and capping options available

currently in the UK. The importance of integrated leachate and gas management systems is stressed and aids to design and construction such as Risk Assessment and Construction Quality Assurance (CQA) are described. Particular challenges to the modern landfill designer are summarised and the chapter concludes with a case history describing the hydrological performance of experimental clay cap panels of varying slope and installation specifications.

Chapter 5: A comparative assessment of international standards and guidance applied to landfill basal liner and capping designs is delivered within the confines of a study area limited generally to continental Europe and the United States of America. Commentary is given on comparisons to current "best practice" guidance for containment system designs in the UK.

Chapter 6: The design and issue of postal questionnaires to waste regulation authorities in England and Wales to gather data on a selected sample of landfill sites is described. The rationale of gathering data on general site details, void space, waste types, site design concepts, base liner materials, capping designs, gas and leachate control etc. is explained. In addition, the need to identify the effectiveness of "in service" systems in protecting the environment together with data collection of local authority views on waste minimisation, reuse/recycling, incineration and composting is highlighted.

Survey responses are analysed and depicted in chart form to demonstrate the study's major findings, the range of responses and the main data groupings. The surveyed results are presented in summary form as the basis for later consideration in formulating final study conclusions and recommendations.

Chapter 7: This chapter reports on the changes incorporated in the latest version of the European Union Landfill Directive and predicts the likely effect on UK waste management and landfilling practice. Indicators suggest that the future role of landfilling in the UK will be in support of more intensive waste pre-treatment and transformation technologies. The role of landfill is expected to diminish from its present lead role; but to what degree and how rapidly remains unclear. The impact

of these predicted changes is debated.

Chapter 8: The main findings of the study programme are summarised. A discussion on the results obtained from the study compared to the anticipated outcomes is presented. Deficiencies in the study approach are considered and areas for further and continuing research are suggested.

2. CHAPTER 2 - WASTE AND WASTE MANAGEMENT

2.1. Waste Production

The dawn of our modern technological society is linked to the start of the Industrial Revolution in Europe. In parallel with society's technological advancement the generation of solid wastes multiplied and an urgent need for sustainable solid waste management and disposal was eventually recognised. Conditions in nineteenth-century England became so poor as to require legislation in 1888 forbidding the disposal of solid wastes into ditches, rivers, and waters. Similarly, eleven years later in 1899 the Rivers and Harbours Act was enacted in the United States to curb the dumping of debris in navigable waters and adjacent lands.

Now, with the assistance of modern production methods, improved product placement and an over-use of consumer packaging the difficulties associated with the management and disposal of expanding volumes of wastes are becoming ever multiplied as the earth's natural resources and buffering processes become depleted. In the modern urban setting the build up of solid wastes has become a direct consequence of life (Tchobanoglous, et al (1993)). An illustration of how and where solid wastes are generated in our high-tech society is shown in simplified form in the materials flow diagram presented as Figure 2.1.

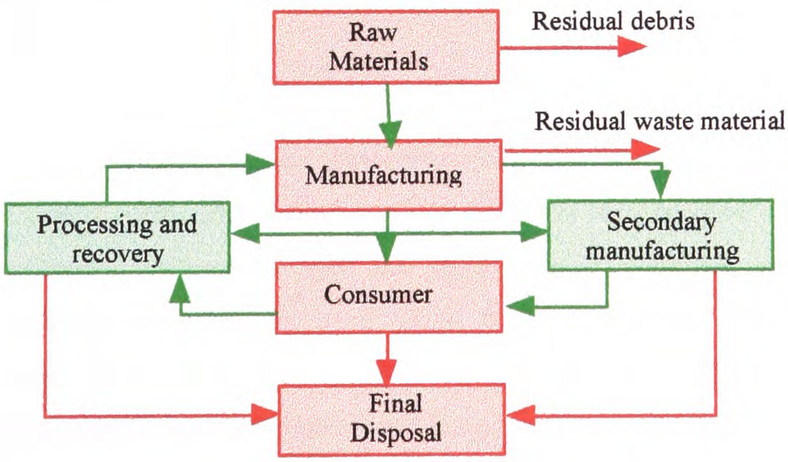

Figure 2.1: Raw Material and Waste Flow Diagram (Tchobanoglous et al)

Solid wastes (or debris) are produced at the outset of a process, commencing, for example, with the winning of virgin materials. The debris (or spoil) arising from mining operations is a well known example. Thereafter, solid wastes are generated at every stage as raw materials are turned into end user products.

A clear way of minimising the quantity of solid wastes needing disposal is to limit extraction of raw materials and to maximise materials recovery and reuse. This is not a difficult notion, but introducing this logical principle into our modern technological society has proved to be difficult. Rather, society has elected to improve waste landfilling and disposal techniques to cater for ever increasing volumes of waste residues. The search for new permanent locations in which to place solid waste has continued and intensified. However, unlike water-borne and air-dispersed wastes, solid waste will not go away. Where solid waste is buried there it will be found in the future - the degree of decomposition being dependent on burial and management techniques at the point of diposal. Lately, the situation has reached overload, as in the South East of England, where disposal void resources are now recognised as deficient. As this is in an area of high population the scarcity of void space may actually assist in driving the re-education of the public in embracing the uptake of waste minimisation, materials recovery, transformation and reuse. Landfill will continue to have a role but a supporting one as part of an integrated waste management philosophy.

2.2. Waste Composition

Effective design of all waste management facilities including disposal sites relies on accurate data relating to waste generation and composition. The recognition of trends in waste types will enable such facilities to be designed for efficient and reliable operation throughout their life span. As an example, landfill liner and leachate management systems need to be designed to cope with the estimated leachate load. The leachate generation characteristic will depend on the waste type - its ability to degrade and produce liquid by-products or alternatively in the case of paper wastes etc. the materials absorptive capacity. All of these elements affect the leachate production rate. There is an ongoing need for the "real time" compilation

of waste data and their evaluation in the forecast of future conditions.

Our modern civilisation has a fixation with the attractive packaging of retail products and this results in constant change in the parameters to be studied in the design of solid waste facilities. Distinctive trends include the increasing use of plastics and the use of frozen or prepared foods. Although this has led to a decline in food wastes in the home it has merely brought about a growth in the waste volumes generated at agricultural and food processing plants as a result.

A typical make-up of components in residential Municipal Solid Waste (MSW) for low-income, middle-income and upper-income countries (recycled materials excluded) is shown in Table 2.1. One can readily assign the term low-technology to the low-income countries and high-technology to the upper-income countries. The table shows variations between the rich and poor countries to-day but can also be used to provide a timeline picture of how the waste stream has developed throughout this century as technology has advanced in the developed nations.

Waste Component	Low-income Countries	Middle-income Countries	Upper-income Countries
Organic:			
Food wastes	40-85	20-65	6-30
Paper			20-45
	1-10	8-30	
Cardboard			5-15
Plastics	1-5	2-6	2-8
Textiles	1-5	2-10	2-6
Rubber			0-2
	1-5	1-4	
Leather			0-2
Yard Wastes			10-20
	1-5	1-10	
Wood			1-4
Misc. Organics	-	-	-
Inorganic:			
Glass	1-10	1-10	4-12
Tin Cans	-	-	2-8
Aluminium	1-5	1-5	0-1
Other Metal	-	-	1-4
Dirt, Ash etc..	1-40	1-30	0-10

Table 2.1: Distribution of Waste Components in Low, Middle & Upper Income Countries. *(- denotes no data)* (Tchobanoglous et al)

Worthy of note is the higher percentage of household food waste in the low technology countries. This is linked to the lesser reliance on the factory processing of foods and the lack of packaging. With more technology, packaging use has tended to increase and this is mirrored by the higher proportion of paper, cardboard, plastic, glass, tin cans etc. in the upper-income/more developed communities. Also of interest is the reduction in the amount of dirt and ash in the upper income population. Upper income society will have access to heating technologies including gas and electric systems where the production of ash in the home environment is absent. Low income communities will remain reliant upon open fires for heating through either coal or wood - with attendant production of ash. As technology has developed in the United Kingdom we have successfully moved through the "ash tip" phase where the major component of waste was ash and cinders from domestic fires in the early half of this century.

A simple comparison such as that given in Table 2.1 gives much useful information to designers when considering the engineering parameters for landfills and other solid waste facilities in different countries throughout the world. A thorough understanding of the contemporary waste stream and accurate prophecy of changes in waste-stream properties throughout the life of the waste facility is crucial to the success of any waste management scheme.

Further data on waste composition has been collected from a variety of recent studies, details of which are set out briefly in the paragraphs that follow.

United States:

In sampling wastes from a closed landfill in Pennsylvania, as part of a plan to re-excavate and re-cycle useful materials in the buried waste stream, the waste make up tabulated overleaf in Table 2.2 was recorded. The combined percentage of paper, plastic, metal and textiles exceeds 50% of the total, which is in line with the waste mix recorded for upper income countries in Table 2.1. The incentive for the recovery of usable materials is clearly demonstrated.

Waste Type	Percentage (%)
Soil	31
Paper	30
Plastic	12
Garden Waste	7
Metal	6
Textiles	6
Other	8

Table 2.2: Excavated Waste Compositions - Landfill, Pennsylvania, USA - (Warmer Bulletin, May 1995)

United Kingdom: Typical UK composition of household waste by weight has been noted as follows:

Waste Type	Percentage (%)
Paper	29
Vegetable/putrescible	23
Ferrous Metal	8
Glass	8
Non Ferrous Metals	1
Textiles	3
Rubber/Leather/Wood	8
Plastics	7
Fines/Dust/Ash	13

Table 2.3: Waste Composition in United Kingdom - (Barron, J.(1995))

World Cities: A comparison of wastes compositions for a selection of major world cities exhibits the following percentage distribution of typical waste streams.

Waste(%)/ City	Organics	Paper	Plastics	Glass	Textiles	Metals	Residues	Leather/ Rubber/ Wood
Hanoi	51.9	2.7	_	0.5	1.3	0.9	41.4	1.3
Paris	16.3	40.9	8.4	9.4	4.4	3.2	16.5	0.9
Budapest	34.7	20	5.7	6.1	_	4.4	29.4	_
Hong Kong	32	21	16	3	5	3	17	3
Vienna	23.3	33.6	7	10.4	3.1	3.7	16.1	2.8

Table 2.4: International City Wastes - (Warmer Bulletin February 1995)

Poland: A 1995 study indicated the typical household and commercial waste composition in Poland as follows:

Waste Type	Percentage(%)
Fraction < 10mm	10.3
Garbage	33.4
Paper	22.6
Plastic	7.3
Textiles	2.9
Glass	10.6
Metals	4.1
Miscellaneous	8.8

Table 2.5: Polish Waste Composition - Source
(Warmer Bulletin - February 1995)

Sources Of Waste - Modern: The waste types indicated in the tables above are derived from a variety of activities. Typical sources of current day wastes are outlined below:

Source	Typical facilities, activities, or locations where wastes are generated	Types of solid wastes
Residential	Single family and multi-family detached dwellings, low-, medium-, and high-rise apartments, etc.	Food wastes, paper, cardboard,plastics, textiles, leather, yard wastes, wood, glass, tin cans, aluminium, other metals, ashes, street leaves, special wastes (including bulky items, white goods etc.), household hazardous wastes
Commercial	Stores, restaurants, markets, office buildings, hotels, motels, print shops, service stations, auto repair shops, etc.	Paper, cardboard, plastics, wood, food waste, glass, metals, special wastes, hazardous wastes, etc.
Institutional	Schools, hospitals, prisons, government centres	As above in commercial
Construction & Demolition	New construction sites, road repair/renovation sites, building demolition,	Wood, steel, concrete, soil etc.
Municipal services (Excel. treatment facilities)	Street cleaning, landscaping, catch basin cleaning, parks and beaches, other recreational areas	Special wastes, rubbish, street sweepings, landscape and tree trimmings, catch basin debris, general wastes from parks, beaches, and recreational areas
Treatment plant sites; municipal	Water, wastewater, and industrial treatment processes etc.	Treatment plant wastes, principally composed of residual sludges
Municipal solid	All of the above	All of the above
Industrial	Construction, fabrication, light and heavy manufacturing, refineries, chemical plants, power plants, demolition, etc.	Industrial process wastes, scrap materials etc., non-industrial wastes including food wastes, rubbish, ashes, demolition and construction wastes, special wastes,
Agricultural	Field and row crops, orchards, vineyards, dairies, feedlots, farms etc.	Spoiled food wastes agricultural wastes, rubbish, hazardous wastes

Table 2.6: Waste Sources - Modern (Tchobanoglous et al)

Sources Of Waste - Historical: For comparison, origins of waste and waste classifications used in the early part of the twentieth century are listed below:

MSW Class	Sub-class	ORIGINS 1	ORIGINS 2
Municipal refuse	Public refuse	Street manure & litter	
		Sweepings & dust	
		Leaves	
		Droppings from carts	
		Large dead animals	
		Snow	
		Public catchbasin silts	
	Trade refuse	Steam ashes	
		Dry factory wastes	
		Slaughter house waste	
		Rubbish - offices & factories	
		Private catchbasin silts	
	Market refuse	garbage from markets	
		Rubbish/cleanings from	
		Old boxes & barrels	
	Stable refuse	Manure	
		Straw	
		Stable cleanings	
		Fly maggots	
	House refuse	Garbage	Animal matter
			Vegetable matter
			Tin cans
			Small dead animals
		Ashes	Coal & cinders
			Clinker & slate
			Dust
			Glass
			Crockery
			Brick & stone
			Metal fragments
		Rubbish	Building sweepings
			Boxes & barrels
			Wood
			Paper
			Rags
			Excelsior
			Straw
			Leather
			Rubber
			Metal ware
			Bedding
			Old furniture

Table 2.7: Waste Sources - Historical (Tchobanoglous et al)

Note that the public refuse classification of the early 1900s matches today's wastes from municipal sources, trade and market refuse corresponds to waste from residential sources. Stable refuse has today faded out as a waste category while

plastics were non existent in the early 1900s. Of note are the changes in the following categories.

Food Wastes: The amount of residential food wastes collected has changed dramatically over the years as a result of technical improvement and changes in public attitude. Two technological advances which have had a significant impact are, as indicated earlier, the development of the food processing and packaging industry and, particularly in the US, the increasing use of food waste grinders. A recent trend, due to wholesome dietary concerns, is also toward the increasing consumption of raw, rather than processed, vegetables. Data on the effect of this trend is not yet firm although the suspicion is that such a trend would tend to increase the quantity of food wastes.

Paper & Cardboard: The percentage of paper and cardboard found in solid wastes has climbed enormously over the past half century, rising from about 20 percent in the early 1940s to about 40 percent in the early 1990s. It is expected that the use of paper and cardboard will remain stable in the foreseeable future although in the UK the introduction of the Landfill Tax in October 1996 and the recent introduction of new UK Packaging Regulations are expected to have a beneficial impact in terms of waste minimisation and recycling.

Garden Wastes: Restrictions on the burning of garden wastes in developed "clean air" countries has increased significantly the volume of waste from this source requiring disposal. In the US garden waste now represents by weight some 16-24 percent of the MSW waste stream. Diverting these waste from landfill to composting facilities is now being seriously addressed.

Plastics: One of the most startling emergences of new waste materials can be linked to plastics, the use of which has proceeded to escalate over the past 50 years. From being a non-measurable waste in the early 1940s plastics accounted for about 7 to 8 percent, by weight, of the waste stream at the start of the 1990s. It is assumed that the disposal of plastics will continue to rise but not at the high growth rates seen in the last 25 years. Indeed the recovery of plastics from end of life products is a

strategic aim in the development of coherent waste minimisation and recycling programmes.

2.3. Waste Quantities

Background: In the way that waste composition is important to waste facilities design, likewise the amount and rate of production of wastes must be comprehended if cost effective and long lasting systems and facilities are to be developed. Data on waste arisings has been compiled from a number of studies and the details are summarised below to give some background to the scale of waste production.

United Kingdom: It has been estimated that some 0.34 tonnes of household collected waste is produced per annum per head of population in the UK. Taking an average body weight of say, 65kg this represents just over five times the weight of the population. With a UK population of some 50 million this gives an annual figure of about 25 Million tonnes - about 1 tonne per household per year. DETR figures closely mirror this with an estimate of about 27 million tonnes of household refuse produced in the UK in 1997/98. The alarming thing about the latest DETR estimates is that they show a 7.1% growth over 1995/96 figures. It is dramatically and immediately apparent that the quantity of waste produced within modern developed countries is vast and growing fast (Daily Telegraph (Weekend) 29 March 1997).

Latest UK Estimates: From the UK government waste strategy document "Waste Strategy 2000" the latest estimates of waste production within the UK as we enter the new Millennium are:

• Industrial Wastes	21-29 Million tonnes per annum
• Commercial Wastes	49-67 Million tonnes per annum
• Municipal Wastes	About 27 Million tonnes per annum

The figure for municipal wastes mirrors closely the annual estimate set out above. Indicators are that municipal waste tonnages are growing at about 3% per annum. Currently only 8% is being recycled and only 14% of municipal waste has energy recovered from it. Clearly this is a huge waste of resource.

International: At "Green 2" 1997, comparative annual figures for household wastes per person for a selection of developed countries were presented as follows:

Country	Waste Per Head Per Annum kg
United States	744
Norway	538
Luxembourg	504
Netherlands	500
Denmark	399
Germany	374
Switzerland	336
Great Britain	335
Sweden	301
Spain	275
France	260
Italy	249
Austria	216

Table 2.8: International Waste Quantities.
(Gora, E. (1998))

Eire: From "Waste Management - Changing Our Ways" (1998) it is recorded that about 2 Million tonnes of MSW waste was consigned to landfill in Eire in 1995. Landfilling accounted for about 92% of the MSW waste stream with only 8% being recycled. The composition of MSW in Eire was recorded for 1995 as follows:

- Textiles 2%
- Metals 3%
- Plastics 9%
- Glass 7%
- Paper 34%
- Putrescibles 29%
- Other 16%

From the composition figures it is clear that a large percentage of potentially recyclable material is not being utilised.

Strategic waste management targets for Eire over the next fifteen years have been defined as listed below:

- 50% diversion of MSW away from landfill
- 65% reduction in biodegradable wastes landfilled
- Development of environmentally beneficial waste recovery facilities
- 35% of MSW to be recycled
- 50% of construction and demolition wastes to be recycled within 5 years
- 85% of construction and demolition wastes to be recycled within 15 years
- Reduction of landfills from 120 to 20 regional "state of the art" sites.
- 80% reduction in landfill methane emissions over 15 years.

2.4. Integrated Solid Waste Management (ISWM)

Introduction: As demonstrated above the quantities of wastes arising within modern technological economies are huge at the present time and the need for effective management of the situation is clear. Adoption of Integrated Solid Waste Management (ISWM) systems will be needed - as is already recognised by many countries. Key components in the waste generation and disposal chain and a hierarchy for modern waste management systems are now described.

Key Elements: The key elements in the waste generation and disposal chain are:-

- Waste Generation
- Waste landfilling and separation, storage, and processing at source
- Collection
- Separation and processing and transformation of solid wastes
- Transfer and transport
- Disposal

When these components have been evaluated for use, and all of the interfaces and links between them have been matched for effectiveness and economy, the community has developed an integrated waste management system. Integrated Solid

Waste Management can be defined as the selection and application of suitable techniques, technologies, and management programmes to achieve specific waste management goals and objectives. The adoption of various state and federal laws in the US and in Europe the EC Directives on Waste, has resulted in the continual evolution of ISWM systems in pursuit of improving waste minimisation and waste recycling achievements.

Hierarchy: In the US the Environmental Protection Agency has suggested the following hierarchy, or order of rank, for ISWM systems. The ranking proposed by USEPA, with Item 1 at the apex of the attainment pyramid, is as follows:-

1. Source Reduction
2. Recycling
3. Waste Combustion
4. Landfilling

In their book entitled "Integrated Solid Waste Management", Tchobanoglous, Theisen and Vigil propose the following ISWM hierarchy:-

1. Source reduction
2. Recycling
3. **Waste Transformation**
4. Landfilling

Note that the term "**waste transformation**" is used because the description "waste combustion" as used by USEPA is felt to be too narrow to cover all available transformation processes - transformation is not restricted to incineration. A brief explanation of the key ISWM stages is set out in the following paragraphs.

Source Reduction: This is the highest or ultimate rank. Source reduction involves reducing the amount and/or toxicity of the wastes that are generated. Source reduction is the most direct way of controlling the amount of waste, the associated handling cost and the environmental impact. Waste reduction can be accomplished

through better design, manufacture, and packaging of products. A reduction in toxic content, less material content and extended service life are all beneficial attributes. Waste reduction may also be cultivated in the daily activities at the household and at the work place for example by employing selective buying patterns and the active promotion of the reuse of products and materials.

Recycling: The second rank in the hierarchy is recycling. This involves the following activities:-

- Separation and collection of waste materials
- Preparation of these materials for reuse, reprocessing, and remanufacture
- The reuse, reprocessing and remanufacture of these materials

Recycling is seen as a key element in any ISWM programme as it helps to reduce demand on resources and the amount of waste requiring final disposal by landfilling.

Waste Transformation: This represents the third rank in the ISWM hierarchy. It involves the physical, chemical and biological conversion of wastes. The transformations applied to Municipal Solid Wastes are used to achieve the following:-

- To improve the efficiency of the solid waste management operations and systems
- To recover reusable and recyclable materials
- To recover conversion products (e.g. compost) and energy in the form of heat and combustible biogas

The transformation of waste materials usually leads to a reduced use of landfill capacity. The reduction in waste volume through combustion (incineration) is a well known example and this process and others are listed briefly below. The disposal of the persisting but pre-treated waste residues following incineration does, however, pose its own complications. There are concerns over the toxic components, for example persistent heavy metals in higher concentrations, within the incinerator ash

residues which are often directed to final landfill disposal.

Transformation Technologies: Available ISWM Transformation Technologies include Physical, Chemical and Biological processes. Examples within each category are as follows:-

- Physical: Component Separation, Volume Reduction, Size Reduction
- Chemical: Combustion, Pyrolysis,Gasification
- Biological: Aerobic Composting, Anaerobic Digestion, High Solids Anaerobic Digestion

2.5. The Role of Landfilling

Landfilling and ISWM: Although the stages and technologies outlined above can help to control the volumes of waste for final disposal, ultimately something has to be done with the following:-

- The solid wastes that cannot be recycled and which are of no further use
- The residual matter remaining after solid wastes have been separated at a materials recovery facility (MRF)
- The residual matter remaining after recovery of conversion products or energy

There remain only two alternatives available for the long term disposal of solid wastes and residual matter. These are:-

- Disposal in or on the land
- Disposal at sea

As disposal at sea is now increasingly frowned upon, the first alternative, landfilling, usually forms the base of the ISWM hierarchical pyramid. Landfilling involves the controlled disposal of wastes on or in the earth's mantle, and it is by far the most common method for ultimate disposal of solid wastes and residues. Yet landfilling, with its position as the lowest rank in the ISWM hierarchy, offers the least desirable

method of dealing with society's wastes. Nevertheless, despite impositions of landfill taxes in a number of countries there remains currently great dependancy on landfilling as the foremost means of dealing effectively with the great volumes of waste now generated by mankind. With this reliance on landfill, which is likely to continue for the foreseeable future, attention has turned to making landfills safer with the goal of safeguarding natural assets such as clean groundwaters and atmospheres. In parallel, however, the increasing refinement of waste transformation or pre-treatment processes will continue with the ultimate aim that these take on the prime role in the waste management arsenal, leaving landfill facilities to cater primarily for the pre-treated residues.

This will have to come about quickly as the need to secure evermore landfill voids in the developed nations is becoming more and more difficult. Reports from the US in the mid 1990's indicated that some states were within 3 years of exhausting their landfill space. (Minor, S.D., Jacobs T.L. (1994))

In the UK it has been predicted that landfill space in the SE of England will be exhausted by 2004.(Daily Telegraph (Weekend) 29 March 1997) This is borne out by the recorded 27% decline of waste void in SE England during 1993 alone. (Warmer Bulletin 42, August 1994)

The UK government's waste strategy document "A Way With Waste" recognises this. Strategy aims include the following:

- Reduction of landfilling for commercial and industrial wastes to 85% of 1998 levels by 2005
- Recovery of 40% of municipal waste and recycling or composting of 25% of household waste by 2005
- Recovery of 45% of municipal waste and recycling or composting of 30% of household waste by 2010

Against this background, great dependence within the UK on landfilling will remain over this timescale. Continued study to understand the processes within modern

landfills will remain an important priority - the development of safer landfills will continue in tandem with the integrated waste minimisation, recycling and waste transformation (or pre-treatment) technologies.

2.6. Chapter 2 Overview

Chapter 2 has revealed the following:

- Waste arises from the raw material, manufacture and consumer processes.
- Waste production has tended to increase with greater technology in society.
- Developed countries produce more packaging wastes - glass, metals plastics.
- Less developed countries produce a greater percentage of "green" waste.
- Waste production per annum per person ranges from 744 Kg in the US to only 216 Kg in Austria.
- Waste quantities currently are vast with great reliance on landfill disposal.
- Landfilling cannot continue at the current pace - there is insufficient sustainable void space.
- Integrated Waste Management Systems will be used in greater number.
- Landfilling will still play an important part - but dealing with a lower volume of pre-treated wastes. Containment will still be a key part of landfill design.

3. CHAPTER 3 - LANDFILL PROCESSES, COMPONENTS AND DESIGN

3.1. Waste Decomposition (after Tchobanoglous et al (1993))

Introduction: A solid waste landfill can be imagined as a biochemical reactor, with solid waste and water as the major inputs, and with landfill gas and leachate as the principal outputs. Material stored in the landfill includes partially biodegraded organic material and the other inorganic materials originally placed in the landfill. Landfill control systems are employed to impede unwanted movement of landfill gas into the atmosphere or the lateral and vertical movement of gas and leachate through the surrounding soil. Recovered landfill gas can be used to produce energy or can be flared under controlled conditions to avert discharge of harmful constituents to the atmosphere. The main stages of waste decomposition are described in the following paragraphs.

Stage 1 - Initial Adjustment: Stage 1 is the initial adjustment phase, in which the organic biodegradable elements in MSW undergo microbial decay as they are placed in the landfill and soon thereafter. In Stage 1, biological decay occurs under aerobic (oxygenated) conditions, because a certain amount of air is trapped within the landfill. The principal sources of both the aerobic and the anaerobic organisms responsible for waste decomposition is the soil material that is used as a daily and final cover. Digested wastewater treatment plant sludge, disposed of in many MSW landfills, and recycled leachate are other sources of microbial organisms.

Stage 2 - Transition Phase: In Stage 2, identified as the transition phase, oxygen is depleted and anaerobic conditions begin to dominate. As the landfill becomes anaerobic, nitrate and sulphate, which can serve as electron acceptors in biological conversion reactions, are often reduced to nitrogen gas and hydrogen sulphide. The onset of anaerobic conditions can be observed by measuring the oxidation/reduction potential of the waste. Reducing conditions sufficient to bring about the reduction of nitrates and sulphates develop at about -50 to -100 millivolts. The generation of methane takes place as the oxidation/reduction potential progressively decreases.

Also in Stage 2, the pH of the leachate, if any is formed, starts to fall due to the presence of organic acids and as a consequence of the elevated concentrations of CO_2 within the landfill

Stage 3 - Acid Phase: In Stage 3, the acid phase, the microbial processes initiated in Stage 2 accelerate with the production of significant amounts of organic acids and lesser amounts of hydrogen gas. The first step, hydrolysis, transforms the higher molecular mass compounds (e.g. lipids, polysacharides, proteins, and nucleic acids) into compounds suitable for use by micro-organisms as a source of energy and cell carbon. The second step in the process (acidogenesis) involves the microbial change of the compounds resulting from the first step into lower-molecular mass intermediate compounds as typified by acetic acid (CH_3COOH) and small concentrations of fulvic and other more complex organic acids. Carbon dioxide (CO_2) is the primary gas generated during Stage 3. Reduced amounts of hydrogen gas (H_2) will also be produced. The micro-organisms participating in this conversion, described collectively as non methanogenic, consist of facultative and obligate anaerobic bacteria. These micro-organisms are often identified in the engineering literature as *acidogens* or *acid formers*.

The pH of the leachate, if formed, will often fall to a value of 5 or lower because of the presence of the organic acids and the elevated concentrations of CO_2 within the landfill. The biochemical oxygen demand (BOD), the chemical oxygen demand (COD), and the conductivity of the leachate will increase significantly during Stage 3 due to the dissolution of the organic acids in the leachate. Also, because of the low pH values in the leachate, a number of inorganic constituents, principally heavy metals, will be solubised during Stage 3. Many essential nutrients are also taken out in the leachate in Stage 3. If leachate is not recycled, the essential nutrients will be lost from the system. It is interesting to note that if leachate is not formed, the conversion products produced during Stage 3 will persist within the landfill as sorbed constituents and in the water held by the waste as defined by the absorptive capacity.

Stage 4 - Methane Fermentation Phase: In Stage 4, the methane fermentation phase, a second group of micro-organisms, which convert the acetic acid and hydrogen gas formed by the acid formers in the acid phase to CH_4 and CO_2, becomes more dominant. In some cases, these organisms will begin to develop towards the end of Stage 3. The micro-organisms responsible for this conversion are strict anaerobes and are called methanogenic. Collectively, they are identified in the literature as methanogens or methane formers. In Stage 4, both methane and acid formation proceed side by side, although the rate of acid formation is significantly reduced.

Because the acids and the hydrogen gas generated by the acid formers have been changed to CH_4 and CO_2 in Stage 4, the pH within the landfill will rise to more neutral values in the range of 6.8 to 8. In turn, the pH of the leachate, if formed, will rise, and the concentration of BOD and COD and the conductivity value of the leachate will be reduced. With higher pH values, fewer inorganic constituents can remain in solution; as a result, the concentration of heavy metals present in the leachate will also reduce.

Stage 5 - Maturation Phase: Stage 5, the maturation phase, proceeds after the readily available biodegradable organic material has been converted to CH_4 and CO_2 in Stage 4. As moisture continues to move through the waste, amounts of the biodegradable material that were previously unavailable, will be converted. The rate of landfill gas generation reduces markedly in Stage 5, as most of the available nutrients have been extracted with the leachate during the previous stages and the substrates that remain in the landfill are more slowly biodegradable. The principal landfill gases produced in Stage 5 are CH_4 and CO_2. Depending on the landfill closure measures, small amounts of nitrogen and oxygen may also be found in the landfill gas. During this maturation stage, the leachate will often contain humic and fulvic acids, which are difficult to process further biologically.

Stage Durations: The span of the individual stages in the generation of landfill gas will adjust depending on the distribution of the organic constituents in the landfill, the availability of nutrients, the moisture content of waste, moisture routing through

the waste fill, and the degree of initial compaction. For example, if several loads of woodland debris are compacted together the carbon/nitrogen ratio and the nutrient balance may not be favourable for the production of landfill gas. Likewise, the generation of landfill gas will be retarded if sufficient moisture is not available. Increasing the density of the material placed in the landfill will decrease the possibility of moisture reaching all parts of the waste and, thus, reduce the rate of bioconversion and gas production. These considerations have been the drivers to those interestested in perfecting the efficient bioreactor landfill - only with systems designed to direct moisture evenly through the waste mass will the goal of achieving stabilisation within a generation be achieved. (ENDS 236, 1994))

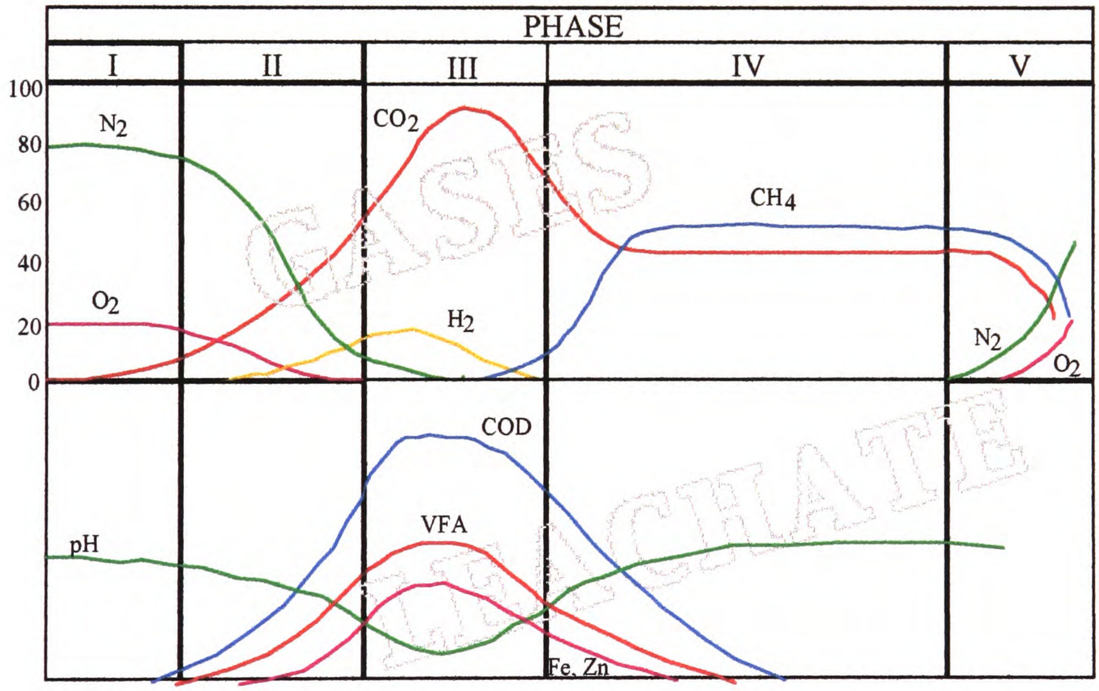

Figure 3.1: Gas and Leachate Phase Curves

3.2. Environmental Concern

Landfill Gas: Landfill gas is comprised of a number of gases that are present in large amounts (the principal gases) and a number of gases that are present in very small amounts (the trace gases). The principal gases are derived from the decay of the organic fraction of MSW. Some of the trace gases, although present in small

quantities, can be harmful and could present risk to public health.

Principal Landfill Gases: Gases found in landfills include ammonia (NH_3), carbon dioxide (CO_2), carbon monoxide (CO), hydrogen (H_2), hydrogen sulphide (H_2S), methane (CH_4), nitrogen (N_2), and oxygen (O_2). The typical percentage make up of gases found in a MSW landfill is reported in the table below:

Gas Component	Percent (Dry Volume)
Methane	45-60
Carbon dioxide	40-60
Nitrogen	2-5
Oxygen	0.1-1.0
Sulphides, disulphides, mercaptans, etc.	0-1.0
Ammonia	0.1-1.0
Hydrogen	0-0.2
Carbon Monoxide	0-0.2
Trace constituents	0.01-0.6

Table 3.1: Landfill Gas Components (by dry volume) (Tchobanoglous et al)

Methane and carbon dioxide are seen to be the principal gases produced from the anaerobic decomposition of the biodegradable organic waste components in MSW. When methane is present in the air in concentrations between 5 and 15 percent, it is explosive. Because only limited amounts of oxygen are present in a landfill when methane concentrations reach this critical level, there is little danger that the landfill will explode. However, methane mixtures in the explosive range can form if landfill gas migrates off-site and mixes with air. The concentration of these gases which may be expected in the leachate will depend on their concentration in the gas phase in contact with the leachate, as estimated using Henry's law. Because carbon dioxide will affect the pH of the leachate, carbonate equilibrium data is also used to

estimate the pH of the leachate.

Trace Landfill Gas Constituents: The California Integrated Waste Management Board has performed an extensive landfill gas sampling program as part of its landfill gas characterisation study. Summary data on the concentrations of trace compounds found in landfill gas samples from 66 landfills are reported in the table below.

Gas Compound	Mean Concentration ppbV
Acetone	6,838
Benzene	2,057
Chlorobenzene	82
Chloroform	245
1,1-Dichloroethane	2,801
Dichloromethane	25,694
1,1-Dichloroethene	130
Diethylene chloride	2,835
trans -1,2-Dichloroethane	36
2,3-Dichloropropane	0
1,2-Dichloropropane	0
Ethylene bromide	0
Ethylene dichloride	59
Ethylene oxide	0
Ethyl benzene	7,334
Methyl ethyl ketone	3,092
1,1,2-Trichloroethane	0
1,1,1-Trichloroethane	615
Trichloroethylene	2,079
Toluene	34,907
1,1,2,2-Tetrachloroethane	246
Tetrachloroethylene	5,244
Vinyl chloride	3,508
Styrenes	1,517
Vinyl Acetate	5,663
Xylenes	2,651

Table 3.2: Trace Landfill Gas Constituents (Tchobanoglous et al)

In another study conducted in England, gas samples were collected from three different landfills and analysed for 154 compounds. A total of 116 organic

compounds were found in landfill gas . Many of the compounds found would be classified as volatile organic compounds (VOC's). The data presented in the above table are representative of the trace compounds found at most long established MSW landfills. The presence of these gases in the leachate that is removed from the landfill will depend on their concentrations in the landfill gas in contact with the leachate. Expected concentrations of these constituents in the leachate can be estimated using Henry's law. It should be noted also that the occurrence of significant concentrations of VOC's in landfill gas is associated with older landfills that accepted industrial and commercial waste containing VOC's. In newer landfills in which the disposal of hazardous waste has been banned, the concentrations of VOC's in the landfill gas have been extremely low.

Landfill Gas and the Earth's Atmosphere: As described earlier landfill gas comprises principally methane (CH_4) 60% and carbon dioxide (CO_2) 40% by volume. It is estimated that 32% of man made methane emissions in Europe are associated with waste sources - 30.8% of which is from landfill. This compares to a figure of 50% of methane derived from agriculture with the remainder linked to energy production.

Methane gas generation rates for MSW deposits have been estimated in the range 35 Kg CH_4 - 76 Kg CH_4/tonne of waste. A 1992 EC study advises a methane generation figure of 55 Kg CH_4/tonne of waste. Reassessment of UK statistics for methane emissions from landfill indicate that between 1.6 - 2.4 Mt/year is released into the atmosphere (Wallis)

Methane is known to be about 25 - 50 times as potent to the atmosphere as carbon dioxide in respect of global warming. With the current concerns over the "greenhouse effect" and the depletion of atmospheric ozone the potential harm caused by landfill methane is clear.

In addition, methane is flammable in air at a range of 5% - 15% by volume with an appropriate ignition source and sufficient oxygen. Carbon dioxide is also well known as an asphyxiant - normally present in air at 0.03% by volume.

Public concern over landfill gas has heightened over recent years following a small number of highly publicised incidents - notably Loscoe in the UK where a bungalow was destroyed by explosion. The potentially disastrous properties of landfill gas are now well known and the need for appropriate controls close to landfill developments in the UK are highlighted in Waste Management Paper 27 - The Control of Landfill Gas. (WMP No. 27, 1989)

Thus in designing modern landfills the management of landfill gas is an important issue to be considered in conjunction with the containment barriers and leachate management systems. The magnitude and rate of gas generation needs to be assessed in order to plan gas flaring or energy from waste systems. Accurate assessments of gas generation are commonly derived from first order decay models. One such model is that produced by the United States Environmental Protection Agency - it is called LANDGEM (LANDfill Gas EMissions). An example, from the writer's own direct project management experience, of the power of this software model is demonstrated in **Appendix 1** where landfill waste placement is modelled over a 30 year period through different phases of landfilling. From this data landfill flare and energy from waste engine capacities can be matched to provide a comprehensive landfill gas management plan to the regulating authorities. As well as principal landfill gases, the LANDGEM model also has the ability to predict the production of trace elements within the landfill gas.

Landfill Leachate: Leachate may be defined as liquid that has percolated through solid waste and has removed dissolved or suspended materials. In most landfills leachate is composed of the liquid that has entered the landfill from external sources, such as surface drainage, rainfall, groundwater and water from underground springs (and old mineral workings) plus, of course, the stronger liquors arising from the break down of the biodegradable wastes, if any.

Leachate Quantities: The capacity for the formation of leachate can be assessed by preparing a water balance for the landfill. The water balance assessment involves summing of the amounts of water entering the landfill and subtracting the amounts

of water consumed in chemical reactions and the quantity leaving as water vapour. The leachate freely available is the quantity of water in excess of the moisture-holding capacity of the landfill materials.

In the water balance assessment the principal sources include the water entering the landfill cell from outside, the moisture in the solid waste, the moisture in the cover material, and the moisture in any sludge or liquid wastes if those are allowed. The principal losses are the water leaving the landfill as part of the landfill gas (i.e. water used in the production of the gas), as saturated water vapour in the landfill gas, and as leachate.

Again from the writer's own direct project management experience, a typical landfill leachate water balance computation is included at **Appendix 2**. Leachate generation has been simulated using the basic water balance equation from Waste Management Paper 26B - over a period of about 15 years. Account is taken of rainfall and evapo-transpiration plus run-off differences in active, intermediate and restored tipping areas. Spreadsheet calculation power is readily harnessed for this type of calculation with the leachate production profiles graphically presented showing mean production profiles as well as quarterly peaks and troughs in leachate quantities. This prediction is conveniently used by the landfill designer in assessing gravity discharge and pumping requirements.

Leachate Composition: When water seeps though solid wastes that are undergoing decay both biological materials and chemical constituents are leached into solution. Representative data on the characteristics of landfill leachate are shown in the Table 3.3 overpage for mature and younger landfills. Although typical values for younger landfills have been given, the range of observed concentrations of the various constituents can be large and great care should be taken when selecting precise values. The biodegradability of the leachate will vary with time and changes in biodegradability can be monitored by checking the ratio BOD/COD. Initially ratios will be in the range 0.5 or greater indicating that the organic fraction within the leachate is readily biodegradable. Mature landfills have a BOD/COD ratio of the order of 0.05-0.2 as the humic and fulvic acids they contain are not readily degraded.

Leachate Constituent	Typical Value mg/L: New Landfill (under 2 years old)	Typical Value mg/L: Mature landfill (over 10 years old)
BOD5 (5-day biological oxygen demand)	10000	100-200
TOC (total organic carbon)	6000	80-160
COD (chemical oxygen demand)	18000	100-500
Total suspended solids	500	100-400
Organic nitrogen	200	80-120
Ammonia nitrogen	200	20-40
Nitrate	25	5-10
Total phosphorous	30	5-10
Ortho phosphorous	20	4-8
Alkalinity as CaCO3	3000	200-1000
pH	6	6.6-7.5
Total Hardness as CaCO3	3500	200-500
Calcium	1000	100-400
Magnesium	250	50-200
Potassium	300	50-400

Table 3.3: Leachate Constituents For New And Mature Landfills (Tchobanoglous et al)

Typical physical, chemical and biological monitoring parameters that are routinely used to characterise leachate are set out in the Table 3.4 overleaf. It is also recognised that impermeable cap systems give rise to lower leachate volumes but that these are of higher strength. Selection of impermeable caps can restrict flushing of the waste mass leading to longer process completion periods. (Ella, P. (1993)). Standard requirements for quarterly, six-monthly and annual monitoring requirements for UK landfill developments are set out in Waste Management Paper No.4 - Waste Licensing. (WMP No. 4 (1994))

Landfill Leachate And Natural Water Systems The major worry with landfill leachate breakout beyond the landfill is its effect on surface waters and groundwaters. Processes that play a part in the attenuation of constituents, as the leachate travels through the subsurface soils include mechanical filtration, precipitation and co-precipitation, sorption (including ion exchange), gaseous exchange, dilution and dispersion, and microbial activity. The fate of heavy metals and trace organics, the two constituents of greatest interest, is considered briefly in the following sub-sections.

Physical Characteristics	Organic Constituents	Inorganic Constituents	Biological Characteristics
Appearance	Organic chemicals	Suspended solids(SS), total dissolved solids(TDS)	BOD
pH	Phenols	Volatile suspended solids(VSS), volatile dissolved solids(VDS)	Coliform bacteria (total, fecal, fecal streptococci)
Oxidation-reduction potential	COD	Chloride	Standard plate count
Conductivity	TOC	Sulphate	
Colour	Volatile acids	Phosphate	
Turbidity	Tannins, lignins	Alkalinity and acidity	
Temperature	Organic-N	Nitrate-N	
Odour	Ether soluble (oil, grease)	Nitrite-N	
	Methylene blue active substances (MBAS)	Ammonia-N	
	Organic functional groups as required	Sodium	
	Chlorinated hydrocarbons	Potassium	
		Calcium	
		Magnesium	
		Hardness	
		Heavy metals (Pb, Cu, Ni, Cr, Zn, Cd, Fe, Mn, Hg, Ba, Ag)	
		Arsenic	
		Cyanide	
		Fluoride	
		Selenium	

Table 3.4: Typical Monitoring Determinants For Landfill Leachates (Tchobanoglous et al (1993))

Heavy Metals In Landfill Leachate: In general, heavy metals are removed by ion exchange reactions as leachate travels through the soil. The ability of soil to detain the heavy metals found in leachate is a function of the cation exchange capacity (CEC) of the soil. The uptake and release of positively charged ions by a soil is referred to as cation, or base, exchange. The total CEC of a soil is defined as the number of milliequivalents (meq) of cations that 100 grams of soil will adsorb. The CEC of a soil depends on the amount of mineral and organic colloidal matter present

in the soil matrix. Typical CEC values, at a pH value of 7, are 100 to 200 meq/100 g for organic colloids, 40 to 80 meq/100 g for 2:1 clays (montmerillonite minerals used in bentonite mixes), and 5 to 20 meq/100g for 1:1 clays (kaolinite minerals). The reported CEC values are affected by the pH of the solution; they drop to about 10 percent of the given values at a pH value of 4. The CO_2 present in the bottom of landfills will have a tendency to lower the pH of the leachate.

The ability of a clay landfill liner to take up heavy metals can be estimated as follows. Assume that the CEC of the liner material is 100 meq/100 g. If the density of the clay material used in the liner is 2200 Kg/m^3 (specific gravity 2.2) then about 2.2E^6 meq of cations can be adsorbed per cubic metre of liner material. Using a typical value of 20 mg/meq for the heavy metals, the amount of metal that could be adsorbed per cubic metre is equal to 44Kg.. If the concentrations of heavy metals in the leachate was 100 mg/litre, the heavy metals could be removed from about 440,000 litres of leachate. If the permeability of the clay is equal to 1×10^{-9} m/s then (assuming 1m leachate depth) 63 litres would pass through 1m^2 per annum. It would take several thousand years to fully utilise the CEC of the clay. If the amount of leachate allowed to percolate through the liner were limited to one tenth of that value by designing the leachate collection system correctly then the time required to chemically saturate the clay liner would be practically infinite..

Research into the effects on natural soils of acid mine drainage shows that primary minerals may dissolve but that overall hydraulic conductivity remains intact. A reduction in soil cationic exchange capacity of about 50% has been observed. (Yanful, E.K., et al (1995))

Trace Organics In Landfill Leachate: The main process in the removal of trace organics from landfill leachates escaping beyond a landfill is adsorption as the leachate moves through a porous medium. Given suitable conditions this can lead to the retardation of the contaminant front (containing the organic constituents) relative to the liquid with the retained material being subjected to biological and chemical conversion reactions - in some cases rendering the retained material harmless.

The properties of clays and bentonite enhanced soils in this respect have become of particular interest as they not only provide a low permeability barrier but also a filtering effect against harmful substances passing into groundwaters.

In combination with effective containment, the management and treatment of leachate is fundamentally important in protecting the groundwater environment. Leachate treatment processes can include aeration, evaporation, precipitation, oxidation, sedimentation and flotation etc.. These processes may often be combined within an integrated leachate treatment system. The matching of leachate evaporation to the combustion of landfill gas has also been studied - theoretical analysis indicates that sufficient methane is produced in modern landfills to accomplish evaporation of the produced leachate. (Birchler, D.R, et al (1994)) The use of large scale leachate recycle infiltration ponds has also been examined as a means of managing large volumes of leachate where a water cycle balance has been difficult to achieve. (Townsend, T.G. et al (1995))

Leachate stabilisation techniques involving the use of Lime Stabilised Sludge Wastes have also been studied - some enhancement of leachate stabilisation (and enhanced methane generation) was observed. The use of Lime Stabilised Sludge as daily landfill cover appears a safe alternative for the management of wastewater treatment plant residues. (Rhew, R.D., Barlaz, M.A. (1995))

3.3. Landfill Containment Concepts:

Background: Mindful of all these environmental concerns and potential human health hazards, in 1976 the Resource Conservation and Recovery Act (RCRA) was introduced in the United States, followed in 1984 by the Hazardous and Solid Waste Amendments (HSWA). These legislations mandated the United States Environmental Protection Agency (USEPA) to develop standards for the management of both hazardous and non-hazardous waste in the United States in such a manner as to protect human health and the environment.

In response, USEPA, through its track record in field activities and research,

formulated interim guidelines. From these interim guidelines the concept of waste containment has emerged and developed. In simple terms the concept of containing wastes within low permeability linings and caps was adopted as the preferred solution to the problem of waste burial. This approach was selected as being preferable to the previously adopted 'dilute and disperse/attenuate' concepts which were considered to present a higher risk to groundwater resources. Nevertheless the limitations, questions and uncertainties linked with the total reliance on the use of geomembrane sealing layers has long been recognised. (Koerner, R.M.(1986)) The need for strict quality control over the manufacture of geomembranes has also been well documented. (Cadwallader, M.W., Barker, P.W. (1986))

Geosynthetic Solutions: The emergence of appropriate geosynthetic materials has greatly assisted the adoption of containment principles for landfills. This has been acknowledged by USEPA with the issue of certain rules of clarification leading to prescriptive design guidance incorporating natural soils/sands and geosynthetic components for the various functional elements.

Soil barriers are mandated to be at least 3 feet (0.9m) thick for base liners having a permeability or hydraulic conductivity not greater that 1×10^{-9} m/s. For flexible membrane liners USEPA guidance recommends a minimum thickness of 50 mil (2.5mm) for semi-crystalline polyethylene materials. For cover systems low permeability layers of 2 ft (0.6m) thickness and FML capping membranes of 20 mil (1.0mm) thickness are documented in the USEPA guidance. The use of geosynthetic materials in both basal liners and capping applications has accelerated over recent years as product manufacture increases and prices drop. Installation times for geosynthetics are generally shorter than compacted soils, and void enhancements arising from the thinner geosynthetic construction leads to revenue increases for landfill operators. Geosynthetic products now available include:

- Geotextiles as filters and geomembrane cushions.
- Geomembranes as the sealing membrane.
- Geocomposites as leachate/drainage layers.
- GCL's - geocomposite clay liners (eg. Bentomat)

The development and use of geosynthetics in the US has been mirrored in Germany and the Netherlands and now increasingly in the United Kingdom. The Landfill Directives of the European Union embody guidance on the specification of natural or manmade containment systems.

Driving the desire to contain wastes is the need to protect human health and the environment. This reflects the ethos contained in the UK National Rivers Authority - Groundwater Protection Policy 1989 and the 1990 Environmental Protection Act, this being distilled further with respect to waste management with the introduction in 1994 of the Waste Management Licensing Regulations.

Containment, as will be discussed later, is not the total solution. Dry entombment does not encourage efficient waste decomposition although for a significant time the soil/geosynthetic barriers will provide the environmental protection desired. Eventually the barriers will deteriorate and become dysfunctional - potentially giving rise to an escape of harmful leachates. These factors can be addressed through proper risk assessment and this risk based approach is embodied in the design guidance documents for UK landfills such as Waste Management Paper No 26B - Landfill Engineering, Development and Operation. (WMP No. 26B (1995))

The need to complement containment principles with leachate control systems (Landreth R.E. (1990)) has also been recognised. Other complementary measures include gas management systems, added pre-treatment of wastes and/or accelerated waste decomposition by the flushing through of leachates to stabilise wastes within the generation (taken to be 30 years).

Even though the containment principles for modern MSW landfills are considered technologically advanced in accommodating wastes for many decades, these arrangements are relatively simple when compared to the containment requirements for certain hazardous wastes. Consider the design and longevity requirements for transuranic-contaminated soils. The use of geomembranes (potential service life 250 to 1000 years (Koerner, (R 2000)) in this situation, where the design life is required to be 1000 years minimum, is an inadequate solution. Such facilities as the US

DoE's Hanford site incorporate a variety of natural material layers such as fine soils, sands, gravels, basalt rip-rap and asphalt, placed in engineered layers directly over the stabilised waste zone. An examination of the water balance performance, including the reservoir capabilities of the fine soil layers, has been undertaken. Rather than water from the fine soil layer percolating downwards into coarser layers it was found that the water pressure in the fine soil remained lower than that required to drive flow downward. In holding moisture in the fine grained upper layers this allowed time for evaporation and transpiration processes to remove it. (Wing, N.R., Gee, G.W. (1994))

3.4. U.K. Landfill Design History: (after Robinson, N. (1995))

Background: To understand the current level of landfill technology in the UK it is useful to review briefly the historical development of landfill design in Britain.

In the 1950's and 1960's curbs on the development and operation of landfills were scant. By the early 1970's, prior to implementation of the Control of Pollution Act (COPA) in 1974, the River Boards had raised concern about contamination of groundwater. This triggered the UK Government to pursue investigations into the formation, migration and attenuation of leachate from existing landfills. The publication of "The Co-operative Programme of Research on the Behaviour of Hazardous Wastes in Landfill Sites" resulted. This research document focused on attenuation processes, the movement of leachate through the underlying unsaturated zone and led to a common approval for the concept of "dilute and attenuate" landfills. The chief concern from that time has always been the protection of groundwater and since that time two main philosophies have evolved. These are:-

- Dilute and Disperse, and
- Containment.

In the United States the protection of groundwater resources was similarly identified and the need for properly designed soil liners and leachate collection systems recognised. (Pita, F.W., et al (1986))

UK Geology: At that time containment in the UK was not as sophisticated as today's engineered landfills. The term "natural containment" was more correct as it relied on natural, in-situ barriers, utilising the suitable geological conditions found in many parts of the UK and Northern Europe - which has produced deposits of low permeability clays following glacial activity.

Complementing this are extensive formations of outcropping low permeability rocks or mudrocks such as:-

- Palaeozoic Mudrocks (Cambrian Mudstones, Coal Measures).
- Mesozoic Clays (Keuper Marls, Oxford Clay, London Clay etc).

Many of these materials have been worked for generations for use as brick clays, refractory clays, potter clays etc. The bustle of the Industrial Revolution and continuing subsequent extraction has left a large amount of in ground voids which planners generally wish to see reinstated. With this restoration by landfill there has come a certain sustainability to the process in the UK.

Such worked out quarries were viewed as a ready resource for landfill as the low permeability materials would help to minimise escape of leachate into groundwater. Minimal investigation was carried out, possibly because it was recognised that they did not represent total containment but increased the dilute and disperse effect. Many people did consider that they provided total containment. However, all these basically low permeability materials have inhomogenities or potential pollution pathways of some degree caused by the variable depositional processes or due to subsequent weathering conditions. There was no CQA applied at the time to the re-engineering of these voids.

The Ongoing Development of Landfill Design in the UK: "Dilute and disperse" was the start of intentional design in landfill in the UK. Ideas that have been researched and developed from this include:

- Water balance - Study of the water balance in the landfill and its environs.

- Capping - To reduce the through flow of incident rainfall.
- Attenuation - Processes researched to reduce the effect on groundwater including attenuation blankets and co-disposal.
- Co-disposal - The intentional deposition of industrial or difficult wastes with household waste in a manner which utilises the attenuation processes in the landfill site to minimise the impact of the industrial or difficult waste on the environment.
- Basal lining to contain harmful leachates using:-

    - Clay Minerals (Brandl, H.)
    - Flexible Membrane Liners
    - Composite Liners (Clay/FML)
    - Bentonite Enhanced Soils (BES)
    - Geosynthetic Clay Liners (Geotextile/Bentonite Sandwich) (Rogers, D.(1993))

- Leachate Control - to minimise 'driving' heads within the landfill, including leachate recirculation.
- Leachate Treatment.
- Gas Control - passive and active.
- Gas to Energy - power production utilising landfill gas to drive electricity producing engines/turbines.

Emerging Research Areas: Arising from the above many innovative solutions and processes are being considered. However, it is recognised that containment of waste does not provide a total answer in the long term preservation of the environment. Containment barriers are likely to fail before waste decomposition is completed if the latter is not hastened. In particular the impact of certain chemicals on geomembrane permeability has been acknowledged. (Geotextiles and Geomembranes 8 (Anon.), (1989)) & (Mitchell, J.K. (1994))

In the UK one specific school of thought has focused on assisting the bio-reactor

processes within the landfill to bring forward waste stabilisation within about a thirty year time frame. (ENDs 236, 1994) It is acknowledged that this is helped by the continual movement of fluid through the waste mass and consequently the concepts of 'leaky' caps are now being investigated together with the mechanics of effective leachate recirculation.

Contrary to this UK philosophy the European Union has, and is continuing to propose, greater pre-treatment of waste before landfilling. Effectively waste pre-treatment brings forward the decay phase of biodegradable wastes in managed and controllable systems before burial of the final disposal residues. The competing philosophies will be discussed later.

UK Guidance and Legislation: Similar to the guidance issued by the United States EPA (USEPA), the Department of the Environment in the UK publishes Waste Management Papers (WMPs) giving recommendations on landfill operation, design, monitoring and completion. The main relevant WMP's with respect to landfilling are as follows:

- WMP No. 4 - Waste Management Licensing
- WMP No. 26A - Landfill Completion
- WMP No. 26B - Landfill Design, Construction and Operational Practice
- WMP No. 26D - Landfill Monitoring
- WMP No. 26E - Landfill Restoration and Post Closure Management
- WMP No. 27 - The Control of Landfill Gas

All Titles - UK DoE published by Her Majesty's Stationery Office.

These current UK publications place emphasis on risk based design and operation as opposed to the more prescriptive minimum design standard guidance given in other countries. Underpinning these guidance documents the major relevant UK legislation relating to landfill development is listed overleaf:

- Town and Country Planning Act 1990.
- Environmental Protection Act 1990.
- Waste Management Licensing Regulations 1994.
- Landfill Tax Regulations 1996.

The next section continues the review of landfill design standards with an up-date review of UK Current Best Practice and a comparison of international landfill design standards.

3.5. Chapter 3 Overview

Chapter 3 has revealed the following:

- MSW landfills, without pretreatment of wastes, are essentially biochemical reactors with municipal solid waste and water as the major inputs.
- MSW landfill reactions have distinct phases from initial aerobic conditions through the anaerobic stage and then acid formation and methane formation stages.
- The major outputs from landfills are leachate and landfill gas - these products give rise to environmental concern in respect of adverse groundwater and atmospheric impacts respectively.
- To counter these concerns modern landfills are designed around sophisticated containment barriers supported by integrated leachate and gas management systems.
- The history of landfill development in the UK has previously made use of favourable geological conditions where natural clay containment has been available - this has been coined "casual containment".
- Enhanced regulatory influence and the application of greater engineering control with the introduction of new lining and capping materials has now raised the construction standards of modern landfills. They are truly complex engineering structures.

4. UNITED KINGDOM: LANDFILL DESIGN STANDARDS

4.1. UK Current Best Practice

Background: Landfills licensed for wastes that are likely to yield significant quantities of leachate or landfill gas will typically require a liner, except in very rare circumstances. Sites built only for inert wastes or low grade contaminated soil will still require some engineering, dependent on site specific conditions. As stated in the previous section landfills have in the past been confined by non-engineered natural low permeability materials, such as those found in brick clay pits. However, natural materials are extremely variable with some geological materials and depositional environments providing less containment than others. Based on a site investigation and the outcome of a risk assessment, an appropriate liner system can be designed in response to the facility's relationship to groundwater resources and the type of waste to be landfilled. The proposed liner system can now be constructed from a wide range of materials, both natural and man-made. In the UK the key to success is seen as the correct implementation of risk assessment (RA) and construction quality assurance (CQA) as aids to design and construction - rather than the mandatory use of over prescriptive "standards".

4.2. UK Liners

Options: The commonly adopted UK liner systems will include one or a combination of the following:

- Mineral liners - such as reworked and compacted clay to ensure that any natural fissures or permeable bands are destroyed. The target permeability for natural clay liners is $1x10^{-9}$m/s typically 1 metre thick for MSW deposits.
- Bentonite enhanced soils (BES) - the addition of small quantities of bentonite (high quality processed montmerillonite clay) to natural soils to reduce permeability characteristics. (Kenney, T.C., et al (1992)) & (Chaupus, R.P. (1990))

- Flexible membrane liners (FML) or geomembranes - the use of welded polymeric liners with appropriate chemical resistance.
- Composite liners - comprising a welded flexible membrane liner (FML) in association with a mineral liner.
- Multiple liners - comprising various combinations of the above and including complexities such as leachate collection and leak detection layers.
- hydraulic asphaltic concrete membranes - comprising a mixture of asphaltic cement, sand, filler and additives.
- geosynthetic clay liners (GCL's) - bentonite within a geotextile sandwich

Factors governing selection: Selection of the correct liner system is a part of the design methodology where the design engineer will need to heed: the risk to the environment; the materials available on site or to the operator in the general vicinity; the economics of the options; and the risk, long term and short term as perceived by the owner/operator.

Further, liner choice should be considered in association with its sub-grade, under drainage, protection layers, and leachate drainage systems i.e. **As a total liner system.** Proper regard of geotechnical parameters forms an important part of the design process - useful guidance is available for designers with respect to the geotechnical performance of landfill structures. (Jessburger, H.L. (1994))

Obviously, a major factor in the selection of a liner will be the assessed risk to groundwaters. In certain locations depending on the type of waste and the sensitivity and importance of groundwater resources a proposal for landfill development will be refused even if "state of the art" multiple liner engineering containment is proposed. The main factors to be weighed in the selection of a liner system are listed below.

1. ***The Risk:*** The risk falls into one of three categories:

    i. **Low risk** - usually for low polluting wastes or in low risk situations, where often a minimal liner specification is appropriate, for example a

1000 mm thickness of clay.

ii. **Medium risk** - typically most MSW landfills, including domestic, commercial and non-hazardous industrial wastes; frequently a composite lining is required, e.g. an FML over engineered clay.

iii. **High risk** - where there are high site specific risks and/or there are special wastes which increase the risk. In this situation an increase in specification over a typical composite liner system, say, a multiple liner system with leak detection and/or an inter liner drainage system, may be required.

2. ***Availability of construction materials:*** The choice of a liner system rests to a large degree on the construction materials conveniently available on or near the site as these high volume materials greatly influence the economics of the site lining. If there is clay on site this is likely to be incorporated as a major part of a composite liner, whereas if sand is available then bentonite enhanced sand (BES) will probably be considered first. The volume of liners should be considered in the economic appraisal as the cost of expensive liners of lower bulk can be offset by more waste being landfilled and the time element of lining with layers that are swiftly installed, or phase extendable can improve the cash flow of a project.

3. ***Type of waste and leachate composition:*** The character of the wastes to be deposited, and in particular the adjustment in composition of the leachate with time should be studied, as both natural and polymeric liners have varying resistance to organic and inorganic chemicals. Most suppliers of manufactured liner materials have charts of how harmful a wide range of chemicals are to their products. However, consideration should be given to specific testing as is carried out in countries such as the US where standardised tests are undertaken (usually to ASTM standards). Within the range of FMLS (also known as geomembranes) there is a wide variety of materials available. High density polyethylene (HDPE) is widely used, because it is one of the most resistant materials to chemical attack. The material's tendency towards Environmental Stress Cracking (including seam

weld areas) has been recognised leading to a need for careful consideration of design factors including the provision of leak collection layers and composite lining systems. (Halse, Y.H., et al (1989), (Lustiger, A., Rosenberg, J.), (Thomas, R.W., et al) & (Agricola, K.R., et al (1990))

Other geomembranes made of different polymers and polymeric alloys have other desirable properties and it is likely that within new liner materials will continue to be developed for landfills. There is current interest in the use of polypropylene liners. (Shah, B.A., Frobel, R.K.(1993))

Natural clays and bentonite-enriched soils can also be affected by some leachate types. This can be combated for organic pollutants by considering the use of organo-modified clays to remove/retard the movement of these pollutants. (Lo, I.M.C, et al (1997))

4. ***Site constraints:*** Physical limits to the design should be assessed such as the slope angles. The angle of internal friction between some FMLs and mineral liners can restrict the angle of the lining slope severely. Combinations of geomembranes, geonets, geotextiles and natural drainage and protection layers should be carefully matched to avoid slippage problems. Sophisticated slope stability studies are often required to assess system/subgrade stability and inter-component slope stability. From the author's own project management experience an example of a geotechnical stability review and appraisal for a major landfill development is included in **Appendix 3**.

5. ***Groundwater:*** Often, sites with significant groundwater ingress or those positioned below a water table may not be acceptable for landfilling of any but inert wastes, particularly where there is "usable groundwater" present or at risk, by virtue of the Groundwater Directive (EC, 1979). Even for sites in or directly underlain by low permeability materials, the foundations should be designed to control any seepage and hydrostatic pressures. The presence of discontinuities or heterogeneities, such as cracks and sand

lenses, in the foundation soil can provide potentially high permeability migration pathways allowing uncontrolled leachate escape. Liners have failed during installation because of base heave and piping caused by excessive hydrostatic head. In addition, soft spots in the foundation soils due to seepage can cause differential settlement and possible disruption/damage to the liner and/or leachate collection system. (Mitchell et al., 1990)

Groundwater and/or surface water ingress can contribute to high pore water pressures and low shear resistances between the various elements of the liner system, resulting in instability/failure of the liner system or structure as a whole (Mitchell et al., 1990). As part of the site assessment and design the following need to be taken into account:

- Depth to nearest water bearing horizon.
- Confined or unconfined aquifer.
- Maximum and minimum water levels relative to site formation level (unconfined conditions) or piezometric head (confined) - both seasonal and long term.
- Permeability of water bearing/confining layers (primary and secondary), and of liner system elements.

Liner Selection Summary: The underlying rule is to understand the materials, their physical and chemical characteristics and constraints, and their associated installation techniques and limitations. Furthermore the design should be able to be Construction Quality Assured (CQA'd) to minimise flaws. Only then can a practical and robust liner system be selected, designed and constructed. An example of liner selection based on the simpler jointing requirements of GCL liners (ie no heat welding) is given by Dunfermline District Council's in-house designs for their Lochhead Landfill liner system. (Waste Management February 1993)

In UK landfill liner installations the relative advantages and constraints of different liner concepts are summarised in the table overleaf:

LINER TYPE	APPLICATIONS	ADVANTAGES	LIMITATIONS
Natural Mineral	- Low risk sites - Non aquifer resource protection zone - Generally on cohesive subbase - Also used on cohesive subbase and multiple liner systems - Low leachate heads	- Side slopes up to 1 in 2.5: - "Christmas tree" construction on steep slopes - Cohesive soils can be improved in-situ - Robust - Natural attenuator - Relatively cheap - Simple structure	- Variable consistency of source material - Susceptible to shrinkage and swelling - Can be susceptible to leachate attack - Protective covering required - Leaky - Low leachate heads - Weather conditions influence workability, compactability and stability
Bentonite Enhanced Soils	- Low risk sites - Can be used as a layer in a multiple or composite liner	- Thinner layers may be achievable compared to natural mineral liner - Side slopes of up to 1 in 2.5	- Limited experience in UK - Specific testing of leachate compatibility
Flexible Membrane Liners	- Generally used in composite and multiple systems	- Very thin - Chemically resistant - Easy to join and patch - Very low permeability - Flexible - Easy to inspect	- Installation damage - Flaws in welded seams - HDPE susceptible to stress cracking - Low friction between liner and soil - Protective covering required - Susceptible to creep - Side slope constrained by stability considerations - No natural attenuator
Composite	- Medium risk site containment - Major and minor aquifer resource protection zones	- Reduced leakage rates - Textured geomembranes increase friction between liner and soil - Layered system - Relatively simple structure	- Clay layer susceptible to shrinkage and swelling - Low friction between liner and soil - Protective covering required - Side slope constrained by stability considerations
Multiple	- High risk sites - Major and minor aquifer resource protection zones	- Layered system - Interlayer leachate systems - Leak detection systems	- Protective layer require - Low friction between liner and soil - Difficult to construct - Complex structure
Hydraulic Asphaltic Concrete	- High risk sites	- Side slopes up to 1 in 1.5 - No protective layer required - Sustains mechanical loads - Trafficable - Relatively easy to repair if damaged -Relatively fast construction	- Soluble in hydrocarbon derived chemicals - Relatively expensive - Lack of experience in UK

Table 4.1 - United Kingdom Landfill Design Options (Street et al 1996)

4.3. UK Capping Systems

Introduction: Landfill capping and cover systems have an assortment of functions. Of fundamental importance is the reduction, or elimination, of infiltrating water derived chiefly from precipitation. This reduces leachate quantity and gas generation and hence treatment and control costs, therefore reducing the pollution threat from the waste body in the short term.

To protect human health and the environment, capping and cover designs should also provide a long-term barrier between the waste and its surrounding environment. This should incorporate a final restoration profile allowing for the reuse of land after landfilling operations have ceased.

Effective capping would also be required during the operation of a flushing bio-reactors landfill in order to control rates of circulation of leachate beneath the cap.

Finally, such systems must allow the monitoring of performance, as well as maintenance and repair (if necessary) to be carried out, ensuring continued reliability and stability of the capping/cover design.

Available UK Options: The character of the capping/cover design is often dependent on site specific conditions. A final cover system commonly incorporates more than one component layer and may include vegetation, soil cover, drainage layers (water and gas), sealing and basal regulating layers. The elements of a model cover system are summarised in Figure 4.1.

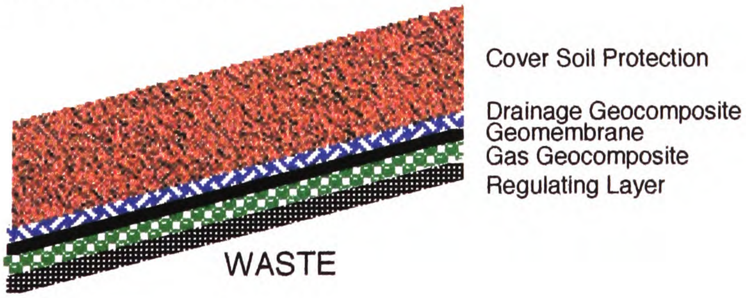

Figure 4.1 - UK Model Landfill Cap

One or more materials may be used within each component layer in order to execute the design requirements. For example, the low permeability sealing layer can comprise natural minerals, synthetic polymers, or combinations of both.

Other layers may also be included into a cover design, such as a biotic barrier, a protection layer and/or a leak detection layer in response to specific engineering preference or licence requirements. Material types, their properties and engineering specifications for each of these layers are discussed in the sections that follow.

The currently available capping systems comprise chiefly:

- Mineral capping layers - most commonly used throughout the UK and employing reworked and compacted clay. Construction Quality Assurance (CQA) is very important for compacted clay liners. (Daniel, D.E.(1990)) & (Nordquist, J.E. (1990)).
- Bentonite Enhanced Soils (BES) - involving the addition of small quantities of bentonite to natural soils to enhance permeability characteristics.
- Flexible membranes and geomembranes - for capping layers these can either be welded or overlapped. Again CQA validation is important.
- Composite capping layers - comprising a flexible membrane in association with a mineral layer.
- Multiple capping layers - comprising various combinations of the above (with leak detection layer where appropriate).
- GCLs - geosynthetic clay liners comprising a bentonite layer between two layers of geotextile. Quality and durability concerns include static confining stress of the bentonite and the efficient needle punched linkage of the two geotextiles particularly in slope applications. (Petrov, R.J., et al (1997))

Capping Systems - Applications and Limitations: Within the UK context, the most widely used capping system has been compacted clay, although in more recent years alternative systems, particularly utilising BES and flexible membrane liners (FMLs), have become more common. In selecting appropriate capping systems it is necessary to consider a number of mainly site specific factors as presented overleaf.

- ***View of the Environment Agency:*** In particular the Agency will usually look critically at capping design to assess how it is likely to influence the potential for leachate generation, both in the short term and the longer term.

- ***Availability of construction materials:*** If there is a good quality clay available on site it is likely that this will be used either on its own or as part of a composite system. If sand is available then a bentonite enhanced sand capping layer is likely to be most economic. By definition capping layers are constructed on completion of each phase of filling and therefore economics is a critical consideration - often the site owner will seek to control costs but it is essential to ensure that this does not prejudice the overall long term performance of the capping system.

- ***Site constraints:*** Physical constraints should be carefully considered, particularly final slope angles. The capping system needs to be carefully designed to ensure that soil layers or intermediate capping layers do not slip. Unfortunately there have been examples of this happening on UK sites where inadequate care has been taken at the design stage.

- ***Restoration and after-use:*** After-use is a key consideration for any restored landfill and usually the subject of significant planning control. Careful thought needs to be given to the provision of appropriate restoration layers (subsoil and topsoil) such that they are of adequate quality to support the planting proposed and also to provide sufficient protection to the sealing layer(s).

- ***Gas Control:*** Recognition should be given to the provision of a gas venting layer within the capping system. The aim should be to provide a system capable of picking up gas emissions over the whole surface of the waste. In designing the venting system attention needs to be given to layer thickness, gas permeability and resistance to aggressive components within landfill gas and its condensate and the potential for encrustation of any stone layers or pipework. The vent systems can be passive or active in nature depending

on the degree of gas control needed. In active systems differential pressure reduction is created to draw the landfill gas to flare or gas to energy systems. An increase in the amount of gas to energy schemes is currently recorded with NFFO (Non Fossil Fuel Obligation) grant assistance being available within the UK. Collecting gas wells within the waste mass and along the landfill perimeter are subject to careful design - taking account of the influence zone emanating from each well. Flare or energy from waste utilisation of landfill gas results in a reduction in methane escaping to the atmosphere thus helping to counter greenhouse warming and ozone depletion. With efficient gas management systems an option of overlapping (non welded) geomembrane sealing layers can be considered.

- ***Surface Water Control:*** The final profile of the capping layer and soils used for restoration will have a vital influence on the rate and quantity of surface water run-off. Final slopes should be steep enough to promote runoff but not so steep that there is a potential problem with soil scour or slippage. Slope angles in the range of 1v:15h to 1v:20h (vertical:horizontal) are currently considered to be most appropriate, although steeper angles can be achieved with careful design. In designing surface water control systems appropriate analytical methods should be used for predicting run-off during storm conditions and for sizing collection channels and attenuation lagoons.

- ***Waste Body Stability:*** Equilibrium of the waste body is clearly a key consideration since any significant movement associated with instability is likely to impact upon the integrity of any capping system. Stability assessments should be an integral part of the landfill design process and will depend upon foundation conditions, interaction between the foundation, liner system and waste body, and overall stability of the waste mass. Assessing the stability of the waste mass is inherently difficult due to the heterogeneous nature of most wastes and considerable caution should be applied when undertaking analyses. Potential failure mechanisms include sidewall slope and base failure, pullout of liner systems from anchor trenches, failure through the waste pile (and foundation), failure along the

liner system, failure within caps and covers and excessive settlement. Rate and eveness of waste filling is a critical factor. (Mitchell, J.K., Mitchell, R.A. (1991)) The importance of interface shear strength and axisymmetric strain are also important factors to be considered when selecting geomembrane materials to accommodate waste settlements. Use of materials other than HDPE, such as PVC and VFPE (Very Flexible PolyEthylene) can be considered. (Smith, M.E. (1997))

- ***Settlement:*** This is one of the key considerations for any landfill. No matter how well the waste is compacted some settlement will occur. This can be forecast with some degree of accuracy and due regard needs to be directed to the potential impact of settlement when selecting capping materials and designing the system. (Daniel, D.E., Koerner, R.M (1992))

Settlement alone will not necessarily give rise to a major problem. However, where differential settlement occurs across a site, or relative to the perimeter of a site or phase boundary, this can have serious consequences for capping system integrity. Capping systems can be designed to allow a certain amount of settlement (total and differential), either by using mineral layers (which to a certain degree have self-healing properties) or by using lap-jointed, rather than welded, flexible membranes. Care should be taken to identify where significant differential settlement is likely to occur and to make allowances in the final design of the capping system. The use of "ordinary" soil cover has also been proved to be more beneficial than "mandated" low permeability clay caps in certain situations in the US. The rationale being that settlement and hence cracking of a clay cap would allow more water to enter the waste mass than a more conformable granular soil layer which would not be as susceptible to cracking. Settlement monitoring assisted in demonstrating this to regulators. (Oweis, I.S., et al (1994))

Settlement studies are now being regularly reported and presented for a variety of sites and these provide useful feedback to designers. One study indicates that settlements of up to 50% of waste height can occur within a

15 month period and accordingly current design guidance (20%-25% settlement) may underestimate the magnitude of settlement. (de Stefano, A.B. (1993))

An assessment of GCL's resistance to settlement in contrast to compacted clay liners has been reported in the United States. GCL's were found to accommodate tensile strains of between 1-10% without compromising the mandated hydraulic conductivity of $1x10^{-9}$m/s. (LaGatta, M.D., et al (1997))

- ***Monitoring:*** Monitoring should be an integral part of landfill site operation, both during the filling stages and post restoration. With regard to the capping, consideration should be given to monitoring the following:

  - settlement of the restored surface.
  - stability of the overall structure.
  - infiltration (with the installation of lysimeters beneath the capping system).
  - landfill gas management, within the venting layer.
  - surface water run-off flows.

Failure mechanisms affecting landfill caps in the long term have been reported in US studies. The failure mechanisms include initial flaws in barrier construction, shrink-swell cycles, freeze-thaw cycles, erosion, subsidence, root intrusion and animal intrusion. (Sutter II, G.W., et al (1993))

For most sites it will not be necessary to monitor all of the above; the extent of any monitoring protocol should be determined on the basis of risk, scale of operations and the requirements of the regulatory authorities.

- ***Field Trials:*** In certain cases it is recommended that field trials be undertaken to confirm that capping design permeability can be achieved.

This is particularly relevant when using a mineral layer or bentonite enhanced soil layer within the capping system. The procedures to be followed in undertaking a field trial should essentially be the same as those adopted for liner systems. Important research work has been undertaken linking the importance of identifying a suitable range of moisture content and dry density values to acceptable hydraulic conductivity. (Daniel, D.E., Benson, C.H. (1990)) A further case study of cap hydraulic performance is presented in paragraph 4.7 below.

The infiltration performance of compacted soil liners has also been studied using small ring infiltrometer techniques. (Panno, S.V., et al (1991))

- *Construction Methods:* Construction methods for the installation of capping systems will be very similar to those adopted for liner systems. There are however, certain key factors to consider.

  - The need to provide a regulating or combined gas venting layer on the surface of the waste prior to placement of the sealing layers.
  - The need to provide soil layers as a cover to the sealing layers. This serves to protect the sealing layers and provides a medium for development of a vegetation layer. Consideration should also be given to providing a drainage layer between the soil and sealing layers in order to dissipate hydraulic head and impede infiltration through the capping system.
  - Differential settlement can be minimised by utilising appropriate waste placement and compaction techniques and also, if necessary, by adopting further dynamic compaction techniques prior to construction of the capping system.

4.4. Leachate Drainage Systems - General Guidance

The main UK document providing advice in relation to the management and control of leachate within engineered containment landfills is "Pollution Control Objectives

On The Design, Development And Operation Of Landfills" issued by North West Regional Waste Regulation Officers Group (NWRWROG), 1995.

Other documents for design guidance relating to leachate drainage systems are the German federal government endorsed guidelines, the USEPA guidelines and the latest edition of the ETC8. "Geotechnics of landfills and remedial works" etc.. The North West Regional Waste Regulation Officers Group report provides the following advice.

- The leachate collection system should cover the whole of the base area and up sloping sidewalls.
- The incorporation of a granular drainage blanket, minimum thickness 300 mm, Department of Transport Type B drainage media.
- The site base gradient should be 2% as a minimum to promote effective leachate drainage.
- The drainage layer should be washed free of fines.
- A granular or synthetic filter should be provided above the drainage layer.
- A collection pipe network should be installed within the drainage layer to facilitate leachate movement to a collection area.
- Construction documentation should be retained.

Concerns also exist with respect to biological fouling of leachate collection/disposal systems in the long term. Studies have indicated bacterial adhesion to geotextile wrapping to leachate pipelines. (Rios, N., Gealt, M.A., Drexel University) Reduction in the flow rates of leachate pipelines has also been recorded, of the order of 12% - 100% within time periods of up to 11 months. (Koerner, G.R., Koerner, R.M., Drexel University).

The leachate drainage system may consist of a combined herringbone system of high quality pipes (typically HDPE or polypropylene), overlain by a blanket of granular material for pipe protection and drainage efficiency. (Koerner, G.R.,. et al (1994)) Gravity drainage of leachate can be achieved within the system along basal gradients formed within each cell and directed towards sumps, usually located along the

perimeter margin of each cell. A range of basal profiles have been devised to improve gradients.

The main leachate spine drain should be directed towards a sump and connected either by an up-slope riser to the perimeter crest, or to a vertical manhole (chimney). Vertical manholes or chimneys constructed from perforated concrete rings, slip-form concrete or HDPE and located above the sump have also been used extensively but may suffer lateral movement caused by settlement or from the impact of compaction plant. Where an up-slope riser is used the pipework should be installed up the perimeter batters and benches preferably at the same time as the waste is placed. A protective cover of approved granular fill should be placed over the up-slope risers prior to the placement of refuse. At the top the leachate removal pipe/main spine drain pipework should be enclosed in a suitable secure surface manhole cover. This is to allow access for both leachate monitoring and removal by insertion of a pump assembly when required. The diameter, length and gradient of the pipe should be considered together with the pump specification. Many pump types will not function efficiently at low angles and the atmosphere is potentially explosive and/or very corrosive. Security should also be considered. The spine drain pipework should facilitate insertion of a jetting assembly for pipework cleaning. Access should also be provided for close-circuit TV inspection equipment.

Thought should be given to both the chemical durability and structural strength of any pipes used in the leachate drainage system. HDPE and polypropylene are suitably resistant and have become widely accepted materials. Structural strengths should be assessed from the relevant manufacturer's information sheets. The nature of the granular pipe bedding should also be considered. Calcareous and coal bearing aggregates have generally been avoided as these can be attacked by the leachate. The final design of the drainage system depends on many factors including:

- Probable leachate production rates.
- Proposed leachate extraction rate.
- EA advice/prescription on allowable head of leachate within the landfill.
- Storage capacity needed within system.

The final configuration of a leachate drainage system should achieve a balance between these factors and must be designed upon completion of hydraulic and hydrologic calculations and once the shape and operational programming of the proposed landfill site has been defined. See the leachate water balance example at **Appendix 2**.

4.5. Particular Design Challenges of Landfill Construction

Introduction: The predominant method of disposing of wastes in the UK at present is the infilling of excavations caused by quarrying as opposed to filling primarily above ground i.e. land raising. Generally the design and construction problems of landfilling are greater than for land raising but planning policy has tended towards using landfill as a means of restoring abandoned mineral workings. Where landfilling has been considered from an early stage of the workings a suitable shape can be left or materials may have been left to make up a suitable shape. In most cases, however, the quarrying operation is likely to have been worked to the limit of the ownership and left near vertical walls with little or no land margin remaining. Lining the basal 'saucer' is straight forward but the lining of near vertical walls is one of the major challenges in landfill design, especially where there is likely to be production of leachate and landfill gas. The following observations should be considered:

- ***Basal Liner:*** The basal area is of paramount importance as, however well managed the leachate levels are, there will always be a significant hydrostatic head of leachate acting upon the basal liner. The walls of a landfill may not always be quite as critical, particularly if there is reasonable drainage against the inside of the lining and a good contrast of permeability between the liner and the drainage media: then, in theory, leachate from perched levels will drain to the basal area and gas will vent upwards.

- ***Side Wall Liner:*** The side wall liner systems of landfilled quarries have been commonly constructed from clay or composite liners which zig-zag up the sidewalls (the so-called 'Christmas tree' liner). These are built up in phases ahead of waste placement. The design of the later stages is not

always considered in close enough detail, as the designer or operator may be hoping that a better solution will emerge later. Three major problems have been experienced with "Christmas tree" liners, as follows:

- they can take up a large volume of air space or use up mineral liner resources, rendering the landfill uneconomic.
- their stability is often poor if built too far in advance and especially if constructed as composites with geomembranes incorporated in the design.
- construction quality assurance (CQA) can be difficult and potentially very expensive for such systems. CQA has focused the attention of many on the problems of constructing 'Christmas tree' liners to a specification and being able to demonstrate that they have been constructed to that specification.

Despite these drawbacks, this method of construction can be relatively simple and straightforward on some sites, especially where a composite is not being used.

An alternative to the 'Christmas tree' construction method is the use of geomembranes. Geomembranes taken vertically up a side wall have been used successfully both in the UK and abroad. Generally some means of support is provided, for example double gabions, steel formwork or reinforced earth structures. The annulus between the geomembrane and the sidewall is infilled at the same rate as the waste is deposited at the front. The main drawback to this method is that it has been found to be somewhat expensive and has only provided a single geomembrane liner. A report of steep walled lining experience in the UK describes the use of polystyrene units in a reinforced soil context. (Di Stefano, A.B., Needham, A.D..(1994))

Centrifuge modelling of geotextile reinforced steep clay slopes has also been reported where better performance was observed with the use of “firm” rather than “rigid” foundations. (Porbaha, A., Goodings, D.J. (1996))

Composite liners are difficult to construct to a detailed specification as the need to rapidly backfill does not readily permit normal compaction or CQA procedures to be carried out. Geocomposite clay liners (GCLs) may provide a solution to either primary or composite sidewall construction in the future, as they are versatile, flexible and readily applied to a steep face. However, shear strength parameters within the GCL and construction sequencing must be carefully considered at the design stage.

Any proposal should be designed for site specific problems, both schematically and quantitatively. In these early stages of development such a proposal probably requires a site trial to demonstrate its practicality and for the operatives to learn construction techniques. Furthermore, such a trial should also evaluate the practicality of the proposed specification and CQA programme.

Lining methods for steep walls are a particular issue in the UK because of the large number of disused and worked out quarries. Little experience has been gained elsewhere in the world and development of new practical and reasonably economic systems is urgently required. Innovation in the context of site specific conditions is the only realistic approach at present - linked to a risk appraisal.

Vertical Extensions: One aspect of landfill construction that is a continuing problem is the vertical extension or overlap of new cells over previously deposited wastes. These old wastes are often not engineered with regard to containment and constructing a modern containment liner "piggyback" over waste can encounter significant problems, such as:

- the settlement of the old wastes due to consolidation, putrefaction and rising leachate levels.
- non-uniform consolidation settlement.
- the unpredictable nature of consolidation settlement.
- the inevitability of differential settlement.

- the prejudicial impact on gas and leachate control within the lower cell.

It is over optimistic to attempt to design any liner over such wastes and expect it to be to the same high standards as a new construction. The risk assessment of the new works must recognise these lower standards. However, by using highly flexible geomembranes supported by reinforced mattresses the potential for future damage can be minimised. There will inevitably be problems with drainage gradients unless the liners are very steep. Support mattresses have been constructed from geogrid reinforced stone, stone filled gabion/mattress and, in Europe, disused tyres. Permeability contrasts should be included together with collection systems rather than relying on the new liners to act as a barrier.

4.6. The Role of Risk Assessment in Landfill Design & Construction (after McKendry, P (1995))

Risk Assessment: Before 1995 the benchmark solution to landfill design in geology containing permeable strata had been that of "dilute and disperse". However, with the advent of the groundwater protection initiatives via the then UK National Rivers Authority and the European Council the adoption of "dilute and disperse" designs have lost favour in the face of the preferred "containment" approach.

With a containment solution attention is also focused on the support systems dealing with leachate and gas collection and management. Containment landfills, which can be built and operated to a more defined performance specification, are considered to be a consistent and more robust product than "dilute and disperse".

An important factor is the degree of containment needed when viewed in the context of the groundwater aquifer zoning policy introduced by the UK National Rivers Authority (now EA) in 1992 - in the enactment of the EC Groundwater Protection Directive. The risk assessment approach to landfill containment designs ensures that the correct degree of protection can be "designed in" for a specific site rather than relying upon a standard (prescriptive) specification which in many cases may be

unnecessary, leading to over conservative and over costly designs

Against this background the need for an objective "risk based" assessment methodology for engineered containment designs has been identified.

What is Risk? Risk can be defined as the probability of realising an undesirable outcome. Risk assessment (RA) is a commonly misrepresented process and is often confused with the basic , non-quantitative analysis known as hazard assessment. A hazard is an event which may occur but it is the product of the consequence with the probability of it actually happening that is the basis of the RA approach.

Key questions and stages which make up RA include:

- What can go wrong? - hazard identification
- How likely is it to go wrong? - hazard analysis
- What would happen if it did go wrong? - consequence analysis
- What are the associated risks? - risk determination
- Are the risks acceptable and can they be reduced? - risk appraisal

Through its unbiased rather than emotive approach the useful application of the RA technique has been recognised in the recommended landfill design guidance within UK DoE Waste Management Paper No. 26B (WMP26B) 1995.

Use of the RA process and methodology before that time was often hindered by the lack of suitable and reliable baseline data. Empirical and professional judgments were often used but these judgements did not devalue the output of the RA process, as they could be assigned conservative baseline values adjustable subsequently as part of a sensitivity analysis, to evaluate critical aspects of a landfill containment design. This interactive characteristic of RA enables "what if" scenarios to be fully explored and analysed at the design stage, using PC-based risk models.

Geomembrane Property Data: Data on the chemical and physical properties of the natural and synthetic materials used in engineered containment designs is available

from a variety of sources. A main complaint against the use of HDPE geomembranes in landfill containment systems had been the apparent lack of field data on the environmental performance of such membranes, in the setting of a landfill. It is true that many landfill geomembranes have been in service for over 25 years but until recently there was a shortage of reliable, scientifically documented data, both about the specific type of membrane used and its method of installation, and also any subsequent monitoring of performance. This situation is now being redressed as data on geomembrane performance in a landfill/leachate environment becomes available from operational sites and numerous research studies. In many cases the geomembrane manufacturers are taking the lead in this and detailed material property data sheets are now widely available. Data on the use of HDPE from related sectors such as the chemical processing industry is also available from the following sources.

- UK, RAPRA: Plascams - general properties
- UK, RAPRA: Chemres - chemical resistance
- US: Compendex Plus - general data source

Many references refer to the leachate leakage potential of HDPE membranes, which may arise from the following:

- Leakage due to permeation or via defects such as tears or holes
- Permeation being a function of membrane thickness, liquid composition and differential pressure
- For HDPE, solvent-vapour transmission can be 1-3 orders greater than that of water (1×10^{-14}m/s)
- Liner defects can be a consequence of manufacture (pinholes) or installation (rips /tears)
- Rate of flow through defects depends on leachate head and hydraulic conductivity of the underlying strata

At the design stage a variety of factors have an influence on the potential leakage rate, including basal floor slopes, leachate head limit, membrane thickness, single or composite liners, size/type of leachate collection system and the nature of the

underlying system configuration (ie underlying clay liner, or leak detection layer, type and thickness of protective layers etc.). Classical references in this field conclude that composite liners (geomembrane on compacted clay liner) perform better. Intimate contact between sealing layers is critical. (Walton, J., et al (1997)) & (Giroud, J.P., Bonaparte, R. (1989))

The construction phase, however, is the crucial stage in determining future system function. Construction Quality Assurance (CQA) is vital if the full design performance of the system is to be achieved. With poor CQA for geomembrane systems, up to 75 holes/ha have been reported, compared to 2-3 holes with good CQA procedures - it should be noted that CQA cannot and should not be relied on to produce a defect free system. Details of CQA are explained more fully later.

Two thirds of flaws are commonly related to geomembrane panel welds and it has been shown that with good CQA, seam faults can be reduced from 1 per 10 m of field seam to 1 per 300 m. Likewise defects may arise from the formation of the sub-base, where poor specification and CQA could lead to the inclusion of large or angular aggregates coming into contact with the geomembrane layer. A US study has found that non-CQA composite liner sites have basal leakage rates on average of 65 litres/ha/day compared to CQA'd sites where average expected leakage rates are reduced to 32 litres/ha/day. These results have been recognised to be biased by pore water from consolidation of the soil - taking this into account CQA controlled liners can be expected to pass 30 - 100 times less leakage than non CQA'd liners. (Aitken, M., Roberts, I.(1993)) Work has also been undertaken to relate probability (risk) of field permeability data being less (better) than a specified value, using statistical spreadsheet and chart comparisons. (Benson,C.H., et al (1994))

It must also be remembered that during the operational (waste filling) phase, careless use of heavy plant at the start of a new containment cell can severely distort the underlying membrane, unless adequate protective cover is used; This distortion can directly induce defects or cause initiation of cracks in the geomembrane (HDPE being susceptible to this) which subsequently propagate during later operations or in the post closure life of the landfill. Similarly the placement of the first lift of waste

should be carefully controlled to minimise the potential for sharp/bulky objects which could penetrate the containment system. The use of only household or dustcart waste for this first lift is therefore a sensible precautionary measure.

The value of the available databases depends much upon the requirements of the researcher but a common element in most of the information sources has been a comparative lack of field trials and documented case studies. This has been addressed somewhat by the initiatives in the UK of research bodies such as EPSRC and the Department of Environment (now DETR). However, much dependence is made on industry who must question the merits and pitfalls of acting as a guinea pig in cutting edge research projects. The lack of documented case histories does tend to support the view that the waste management industry had not foreseen the legislative trends which led , in a very short timeframe, to the current dominance of "containment". The industry must now ready itself to be in the forefront of further imminent changes led by the EU towards the uptake of alternative waste management technologies. These include waste minimisation, materials recovery, waste transformation processes and lastly improved disposal technologies possibly incorporating landfill "bioreactor" technology although a non putrescible approach to landfilled residues is currently favoured within the EU.

Identifying hazards: The hazards posed to an engineered containment landfill may arise during the design, construction, operation or post closure phases. The possible consequences which could arise due to these hazards will vary with time for the same event, due to the changing circumstances and conditions within the wastes undergoing stabilisation. Adverse environmental impact may arise from one or a combination of the following:

- Design
  - Inadequate cell floor slopes
  - Inadequate choice of geomembrane thickness/protection layers
  - Inefficient leachate collection system
  - Wrongly specified leachate head
  -

- Construction
  - Ill prepared sub-grade
  - Poor materials quality control/ storage
  - Penetrations through liner containment system (pipe entries etc.)
  - Failure of geomembrane weld seams
  - Poor/ absent Construction Quality Assurance (CQA) procedures

- Operations
  - Poor care when working close to liner system
  - Failure or poor maintenance of leachate drains
  - High rainfall entry
  - Build up of leachate head

- Post closure
  - Failure of capping system
  - Failure of leachate collection system
  - Long term impact of inappropriate wastes

The listing gives an indication of the types of hazard or event that may arise at various times during the life of a landfill. The routes by which these hazardous incidents could occur can be examined using fault trees, which can be quantified to give the likelihood or probability of such events occurring.

Consequence Analysis: What would be the consequence of any of the above hazards occurring? Depending upon the design of the containment system and the surrounding geology/hydrogeology, local habitat etc., a variety of individual consequences could be assigned. However, in simple terms the single most important consequence in nearly all cases is the breaching of the containment system, leading to uncontrolled escape of leachate and/or landfill gas.

The magnitude of any adverse environmental impact arising from these hazards / consequences can be deduced once some assumptions are made. For the analysis to be meaningful it is more beneficial for these assumptions to be realistic rather than theoretical. For example, assuming that the worst case for a synthetic liner is that it "instantaneously" disappears is not really a realistic event and the adverse pollution impacts that derive from this are not really worthy of consideration. Instead, a more

reasoned scenario based on whatever empirical or field experience is available is more likely to provide a useful case study and add to the overall understanding of what could, realistically occur.

The output from the RA of an engineered containment system may in fact be only the first stage in an overall RA study, which could encompass groundwater modelling for a particular site as required under Regulation 15 of the UK Waste Management Regulations 1994. From the various failure scenarios examined for the engineered containment RA phase of the work, the resultant leachate leakage rates and contaminant levels would become the input data to the groundwater RA study; hence the importance of ensuring that the failure scenarios examined are realistic.

The level of technical input to such studies, including both man hours by the client and the costs of any field work associated with installing observation and pumping wells for example should, however , not be underestimated. It is with these costs implications in mind that the regulatory authorities should focus their requests for information on realistic outcome events and not insist that unnecessary or impractical failure scenarios be examined.

Risks and their evaluation: The purpose of this phase of assessment is to determine the likelihood of leakage from a landfill site causing unacceptable contamination, be it leachate contaminating potable water supplies, landfill gas seeping into surrounding strata etc.. The estimation of the likelihood of the failure of the containment system is determined using fault trees, which give a pictorial image of the following questions:

- *Q* What conditions are necessary to produce a significant leachate escape?
- *A* A pathway from the waste to the sub-base combined with leachate generation.
- *Q* What would cause a pathway to exist?
- *A* Failure of the containment system during construction, site operation or post closure failure

Once fault trees have been developed they can be quantified using available data sources - hence the importance of well documented and monitored field trials and landfill site developments. With the requirements for pre-operational, operational and post-operational monitoring of sites under the Environmental Protection Act 1990 and the Waste Management Licensing Regulations 1994 the availability of reliable data should come more readily to hand. The Environment Agency and DoE initiatives in experimental field trials and a national GIS on landfills for the UK will also bear fruit in feeding back useful data. These data can then be used in the RA's for the development of future landfill sites.

The validity of the data used can be questioned and tested, via a sensitivity analysis which allows various interested bodies to test possible final outcomes. The result will be the calculation of a probability outcome for a particular event and associated risk. Once such a system is developed for a particular containment design, other modified designs can be evaluated for their probabilities of failure. A comparative RA can then be undertaken for a set of assumptions and using cost estimates for the construction of the various systems, a relative cost-benefit can also be established.

Debate: The basic principles of quantified risk assessment are well established and have been used in the chemical and nuclear industries for many years. This useful tool is now being used to help in the design and evaluation of landfill development options. The process represents the most logical method of evaluating the probability of a given adverse event, based on the identification and analysis of known or possible hazards, their consequences and the associated risk of that consequence occurring. In the preparation of the logic pathways or fault trees a degree of professional judgment can be employed. However, the availability of reliable scientific data is seen as an essential ingredient in allowing quantification of these fault trees with any degree of confidence. These areas are identified by the DoE and Environment Agency as critical targets for data feedback. A number of key experiments encompassing landfill cap performance, leachate quality, landfill gas generation, best landfill practice etc have been commissioned and reported on and new experiments are currently in progress with data eagerly awaited. The need for "good science" has been recognised with the DoE's landfill design guidance

advocating the benefits of the RA approach in WMP 26B. The DoE has also commissioned the development of a suitable Windows based PC model for evaluating the suitability of existing and proposed landfill development sites. Using a graphical interface this programme can assess potential risks to the environment (in particular groundwater) arising from waste type, site design, site geology / hydrogeology etc.. Feedback on the performance of this simulation software is also awaited with interest within the waste management industry - both from the operator and regulator perspective. Data for these tools should also become more readily available with modern landfill monitoring regimes, waste stability studies and risk analyses required to prove waste stabilisation as a precursor to waste management licence surrender.

The LANDSIM Model: In response to the "risk assessment" requirements of UK Waste Management Paper 26B (Landfill Design, Construction and Operational Practice) the Department of the Environment funded the development a probabilistic computer modelling package called LANDSIM. The package is based around the Windows graphical operating system and provides a probabilistic risk assessment methodology for the impact of landfill sites on the groundwater environment. It calculates the amount of leachate expected to leak from a site and applies this to the underlying geological environment. (Gronow, J., Harris, B. (1996))

The methodology within LANDSIM takes the form of a series of interlinked modules. These modules calculate leachate heads within the landfill, compute leakage volumes from the site; estimate the migration and attenuation of contaminants through the unsaturated zone; and assess the potential impact on a given point within the groundwater environment.

The program employs a Monte Carlo type numerical scheme to propagate uncertainty and for each output type results are represented as probability distributions. Therefore, no single answer exists but a range of values from which the regulator and designer can choose according to the degree of uncertainty present or the sensitivity of the situation.

An example of the LANDSIM methodology and evaluation techniques is set out in **Appendix 4**. The example is taken from the author's own project management experience and considers a multi component waste containment cell and the risk to groundwaters from leachate leakage.

4.7. The Role of Construction Quality Assurance (CQA) in Landfill Construction

Construction Quality Assurance (CQA): Quality systems are the final key to the successful design and development of modern landfills. As well as giving customer confidence the adoption of quality systems encourages a culture of "Right First Time!".

To ensure that the quality of materials and installation will match the designer's wishes it is now normal practice to produce a Construction Quality Assurance Plan (CQAP). This will confirm the minimum material specification requirements, installation methods and the testing and observation records to be maintained to certify correct manufacture and installation of the crucial landfill liner and capping systems. The CQA checks will also review the design from the view of buildability and material/waste compatibility.

Method Statements will then be prepared and these will include the following details:

- method of foundation preparation and acceptance
- method of sub-liner groundwater control (as appropriate)
- method of sub-liner leak detection system installation (as appropriate)
- method of liner construction including plant requirements and also compactive effort in the case of mineral liners
- allowable ambient atmospheric conditions for optimum liner placement - temperature and humidity factors can adversely affect weld quality on geomembrane installations
- for mineral liners the allowable working range of soils classification indices, moisture content and dry density
- methods to wet and dry clays to achieve the placement criteria range for moisture content
- survey control requirements to control layer thickness, line, level and gradient

- procedures and frequncies to be adopted for verification testing of materials as delivered and as installed
- construction technique adjustments for works on slopes
- methods of construction for ancillary works such as leachate drainage and gas control systems
- remedial procedures for the repair of damaged on non-complying area of work
- protection measures to counter inclement weather such as frosts, dessication (of clays) etc.
- method of protection for completed areas of liner
- construction sequence recomendations particularly for composite geosynthetic liners and slope area construction

The form of documentation for the final Construction Quality Assurance Report (CQAR) - that is the means of presenting the results to the regulatory authorities, will also be set out in the CQAP All test results, along with a plan showing sample locations, should be submitted to the regulators. Design changes agreed during contruction should be included together with details of non-compliance incidents and rectification procedures. Specimen CQA proformas, developed from the author's own work experiences, for recording landfill liner and capping installations are included for information in **Appendix 5**.

With all the details of material conformance checks and installation process monitoring documented the CQA Engineer will conclude the CQAR with formal certification that the materials and installed design comply with Designer's specification and the requirements of the CQA Plan. An important aspect of the CQA process is the formal recording of agreed design changes or installation procedures.

Until this process of checks and submissions has been completed and regulator approval received waste placement in the work area cannot proceed. This is seen as an acceptable additional procedural safeguard - necessary to protect the environment against damage from poor design and construction processes - detailed documentation also provides a valuable quality audit trail should future problems occur.

4.8. Case Study: UK Field Trial of Clay Cap Performance (Bickerton, M., Davies, K., et al (1995))

Reported to the UK Department of Environment in the mid-1990's is the result of a two year study on rainfall infiltration into landfill cover systems. The study was conducted by Rust Environmental at the Little Packington landfill - courtesy of BFI / Drinkwater Sabey.

The experimental work involved the construction and monitoring of four adjacent capping test areas, each containing three lysimeter cells. All four areas consisted of a nominal 1 metre thickness of clay (locally sourced Mercia Mudstone), covered by a 5 mm thick synthetic lateral drainage layer and overlain by a nominal 0.5 metre thickness of soil which was grassed. The four areas differed in terms of surface slope (two at 1:10 and two at 1:20) and the specification controls used for placement of the clay layer - two being "engineered" and two "non- engineered".

Comprehensive testing of the clay soils was undertaken - both in the laboratory and in-situ at the test site. Weather data were recorded at the test site, comprising the following parameters:-

- average direct solar radiation
- average shaded solar radiation
- total sunshine
- average net radiation
- average dry temperature
- average wet bulb temperature
- average relative humidity
- average rainfall
- total duration of precipitation

Surface water volumes and infiltration water volumes were measured, via tipping buckets, and logged using the weather station data logging electronics. Soil moisture data were measured via an array of neutron probes at varying depths backed up by a

vertical tensiometer array providing data on soil matric potential. Analysis of data from the study enables a number of conclusions to be drawn concerning the process of rainwater infiltration through landfill cover systems. These include the effect of surface gradient and the engineering 'standard' of the clay capping element.

The general conclusions concerning infiltration through landfill covers of the design tested were:-

- In all four designs, the infiltration rate was in the overall range 1 - 10 mm/year, which is small in comparison with incident rainfall (less than 1%)
- The soil cover layer in each case showed considerable seasonal variation in moisture content, but also responded rapidly to rainfall events
- In each case the top 0.5 metres (approximately) of the clay layer experienced a summer decrease in moisture content. This is due to evapotranspiration losses from above rather than due to downward infiltration
- The results suggest a rapid transmission of water pressure through the cover profile following large rainstorms, with infiltration starting to occur within a few days of the storm - the rate of infiltration due to an individual storm then declining over a period of some 2 - 3 months following the storm
- The infiltration response to individual events appears to be superimposed on a 'background' infiltration rate from general winter rainfall

The effect of surface slope and the engineering standard of clay placement were noted as follows:-

- In general, the differences in slope (1:10 and 1:20) appear to have had little effect on the performance of the cover system, in comparison to variability arising from other factors. In particular the lateral and vertical (upward) soil water movements controlled by the drainage layer and the surface vegetation appear to be more significant factors
- Generally, the differences in clay "engineering" also appear to have had little effect on the behaviour of the cover system in comparison with variability

due to other factors such as the drainage layer and surface vegetation as referred to above

- In three of the four design cases, the structure of the clay layers, as imparted during layered installation (three 330 mm lifts in the 'non-engineered' cases and seven 150 mm lifts in the 'engineered' cases) is apparent in the soil moisture profiles for the clays

From the soils test data the following conclusions were drawn:-

- The range of results of the tri-axial constant head permeability tests carried out on remoulded samples in the laboratory showed a close agreement with the range of infiltration rates measured in-situ via the lysimeter cells
- The range of results of the falling head permeability tests carried out on remoulded samples in the laboratory at moisture contents less than the maximum field moisture content of 30%, showed a close agreement with the range of in-situ permeabilities measured by drive-in piezometers positioned near to the zone of permanent saturation in the landfill liner covering the lysimeter cells

The study reviewed the design decisions for the experiment and commented as follows:-

- The vertical arrays of neutron probes and tensiometer probes provided very useful information in terms of the time varying moisture content and porewater pressure in the soil and clay materials
- The design of the test areas did not allow capture and measurement of all storm run-off, some of which by-passed the run-off collection system
- There were difficulties in obtaining continuous, accurate measurements of the various weather variables for estimation of evapo-transpiration, such that the UK Meteorological Office data for the nearby weather station allows a better estimate of actual evapo-transpiration conditions at the site than did site data
- It would have been interesting to have measured run-off and drainage interflow as separate variables to assess their relative proportions and

assess any time lag involved in interflow

Other Capping Studies: The effectiveness of capping and liner components has also been studied in the United States. The presence of landfill cover in combination with a compacted soil liner (non CQA'd and > $1x10^{-9}$m/s) and leachate collection system reduces leachate percolation rates by about 56%. Without the leachate collection system the reduction in leachate percolation was only 23%. A compacted clay barrier as a capping prevents an additional 33% leachate percolation. (Sophocleous, M., et al (1996))

Comparative studies have also been carried out in the United States comparing water balance measurements from two earthen covered landfills with water balance computer models. The HELP model generally over-predicted whilst the UNSAT-H model generally under-predicted. (Khire, M.V., et al (1997))

4.9. Chapter 4 Overview

Chapter 4 has revealed the following:

- Landfill basal seals in the UK can employ natural mineral (clay) liners, geomembranes, geocomposite clay liners etc..
- Leachate management drainage must be designed as an integral part of the lining system.
- The choice of lining or composite lining will be adjudged on risk appraisal.
- Factors to be considered will include landfill location, groundwater setting, types of waste and leachate composition, available construction materials and specific site constraints such as steep side walls etc..
- UK capping systems can employ natural mineral (clay) liners, geomembranes, geocomposite clay liners etc..
- Gas management systems shall be considered as an integral part of the capping and cover system design.
- Risk will again be appraised for capping designs, and factors to be

considered will include site constraints, available construction materials, settlement effects, surface water control, restoration afteruses etc..

- Risk appraisal and Construction Quality Assurance are cornerstones of modern UK landfill design and construction.
- Research indicates that above cap drainage and evapotranspiration are the major controlling factors in landfill cap performance.
- These factors outweigh the engineering quality of layered placement in the case of clay caps.
- Nevertheless attention to high quality clay cap construction validated by a CQA programme is recommended.
- Above cap drainage systems are critical to overall cap performance and should be CQA'd.
- Evapotranspiration is critical to cap performance - vegetation planting and aftercare programmes should also be subject to detailed CQA attention.

5. CHAPTER 5 - CONTAINMENT: INTERNATIONAL COMPARISONS

5.1. Introduction

Information on varying international standards for landfill liner and capping systems has been gleaned from inspection of two major studies on this subject, (Holzlohner, U. et al (1995) & Forster, A. (1995), plus available USEPA guidance etc.. The range of countries listed includes mainland Europe, United Kingdom, United States and also Japan. Each country is examined in turn in the following paragraphs and details of systems are represented in table form, system layer by system layer, for clarity. An overview comparison of standards is offered at the end of the chapter.

5.2. Austria

Background: The liner structure covered in this section refers to the landfill classes 'industrial landfill', 'incinerator residue landfill' and 'reactor landfill' (landfills for municipal solid waste or waste with biologically degradable organic content). It is not required for inert material landfills. The landfill classes differ mainly in their allowable limiting values for waste eluate concentrations of COD, carbohydrates, halogenated carbohydrates, heavy metals, etc..

Austria - Liners: Details of landfill liner requirements within Austria are as follows:

Component	Required standard
Filter Layer	No requirement. No separating layer between waste and lining system.
Drainage System	Drainage layer thickness 0.3m, area filter, gravel, slope 3%. Drainage pipe HDPE, bore not less than 0.2m, perforated to 2/3 of circumference, inspectable, positioned in middle of drainage layer, longitudinal slope 2%, pipe spacing to hydraulic capacity.
Protective Layer	Non woven geotextile
Geomembrane	HDPE, thickness not less than 2mm
Mineral Layer	Layer thickness 0.6m, compacted in 3 lifts, k not greater than 1x10-10 m/s, natural earths preferred.
Subsoil	Bedrock or in-situ clay soil, groundwater table always below the liner.

Table 5.1 - Austrian Landfill Liner Standards

Austria - Capping: Details of landfill capping requirements within Austria are as follows:-

Component	Required Standard
Capping System	Only modest requirements stated - "a covering" in the form of a geomembrane is sufficient.

Table 5.2 - Austrian Landfill Capping Standards

5.3. Denmark

Background: The liner system described refers to the landfill class 'sanitary landfill'. It is not required for incinerator residue and pulverised fuel ash landfills nor for landfills of other inert wastes.

Denmark - Lining: The concept of controlled leaching tends to hold sway in Denmark with many sites being located in coastal settings. Basal lining requirements are not as onerous as in other countries. Details of Danish lining requirements are set out below:

Component	Required Standard
Drainage System	Drainage layer: layer thickness 0.3m, area filter, gravel or sand with no silt content, transversal slope according to hydraulic design. Drainage pipe: perforated, inspectable, in the middle of the drainage layer, longitudinal slope @ 20m centres max.
Protective Layer	Geotextile of high unit surface weight or gravel/sand mix, layer thickness 0.3m, round grain 20mm min.
Geomembrane	Not obligatory, no general requirements on thickness and material.
Mineral Layer	Layer thickness 0.5m, compacted in 2 lifts, not greater than 1x10-10 m/s, suggested bentonite inclusion, which can be omitted where there is a clay subsoil with a layer thickness equal to or exceeding 2m.
Subsoil	No general requirements, groundwater table to be always below the liner.

Table 5.3 - Danish Landfill Liner Standards

Denmark - Capping: The standards applying to landfill capping in Denmark are as set out overleaf.

Component	Required Standard
Reclamation Layer	Arable soil, layer thickness equal or exceeding 1.7m (for agricultural use).
Drainage System	Drainage layer, layer thickness 0.3m, area filter, gravel or sand. Agricultural drainage pipes laid on the liner, at centres no greater than 20m.
Geomembrane	Not compulsory; no general requirements on thickness and material.
Mineral Layer	Layer thickness 0.5m, compacted, k not greater than 1x10-10m/s.
Regulating Layer	Coarse sand, layer thickness 0.5m, simultaneously used for gas control.

Table 5.4 - Danish Landfill Capping Standards

5.4. Germany

Background: Landfill liner systems construction practice in Germany is based on the requirements of several fundamental documents: TA Abfall (1991) for hazardous waste landfills and TA Siedlungsabfall (1993) for municipal solid waste landfills. For permission to be given to deposit waste on a Municipal Solid Waste landfill its content of certain organic substances and its eluate concentration of certain materials (eg. heavy metals, etc.) may not exceed given limited values. Using these criteria, landfills have two classes - Class 2 more harmful than Class 1.

Germany - Liners: Lining requirements applicable within Germany are as follows:

Component	Required Standard
Filter Layer	None, nor separating layer between waste and liner.
Drainage System	Drainage layer: layer thickness not less than 0.3m, area filter, gravel 16-32mm, kat least 1x10-3m/s(long term), transversal slope 3%. Drainage pipe: HDPE at least 300mm bore, 66% perforated, inspectable, pipe slope 1%, centres less than 30m.
Protective Layer	E.g. non woven geotextile, approx.. 2000g/m2. Tendency towards geocomposite protective layers (sandmats etc.), BAM certification in some States.
Geomembrane	Certified HDPE, not less than 2.5mm thick.
Mineral Layer	Layer thickness not less than 0.75m, compacted in 3 lifts, k not greater than 5x10-10m/s (Class 2 MSW).
Subsoil	Layer thickness not less than 3m, not less than 1x10-7m/s, subgrade 1m above upper groundwater.

Table 5.5 - German Landfill Liner Standards

5.4.5. ***Germany - Caps:*** German capping standards are listed below:

Component	Required Standard
Reclamation Layer	Arable soil, layer thickness not less than 1m.
Drainage System	Drainage layer: layer thickness not less than 0.3m, area filter, k not less than 1x10-3m/s (long term), slope gradient 5%. Drainage pipe: HDPE, bore not less than 250mm, perforated, inspectable, centres according to hydraulic design.
Protective Layer	Can be omitted, since the capping drainage layer only requires an effective grain size of approx.. 1mm for k=1x10-3 (long term) - Ramke, 1991).
Geomembrane	HDPE, not less than 2.5mm - BAM certification required. Recycled allowed for Class 2 MSW if certified.
Mineral Layer	Layer thickness not less than 0.5m, compacted in 2 lifts, k not greater than 5x10-9m/s, Class 2 MSW.
Regulating Layer	Coarse sand, layer thickness not less than 0.5m, also used for gas drainage.
Gas Drainage	Layer thickness not less than 0.3m, calcium carbonate content not more than 10% by weight.

Table 5.6 - German Landfill Capping Standards

5.5. Hungary

Background: The State of the Art in the field of landfill lining technology in the previous Eastern Block countries can be illustrated by the example of Hungary. It should be noted that Hungary is one of the more advanced of these countries. Official documents relating to environmental protection include:

- Council of Ministers Directive 56/1981.(XI. 18) on the origin, control and decontamination of hazardous wastes.
- Its Amendment, i.e. Directive 27/1992(I.30).
- Water Act IV./1964.
- Its implementation, 32/1964.(XII.13).
- Directive 1/1986.(II. 21.) ÉVM-EüM on waste management.

Hungary - Liners: For basal liners there exist neither standards nor guidelines. However, geotechnical investigations are carried out and design proposal for the

landfill will be scrutinised by local councils in consultation with the following:

- geological authority
- health authority
- water authority
- water and sewage works
- land registry

Hungary - Capping: Landfill operators are tasked with maintaining some landfill cover through the operational filling phases - daily cover. On completion the wastes are to be capped to allow grass cover supplemented with bushes and trees. Practice has shown this to be merely a 0.5m cover of topsoil.

5.6. Italy

Background: In Italy the landfill categories 'municipal solid waste landfill' (Class 1), 'hazardous waste landfill' for inert materials and for non or slightly toxic hazardous wastes (Class 2) and 'hazardous waste landfill' for toxic hazardous wastes (Class 3) are recognised. The minimum legal requirements on the basal liners of Classes 1 and 2 demand that an 'impervious' artificial liner should be placed on the subsoil to prevent any leakage of leachate. The permeability of a minimum 1m thick layer of the subsoil beneath the liner must not exceed 10^{-8} m/s. The distance between the lower face of the liner and the groundwater table must be a minimum 1.5m. A drainage system should be laid over the artificial liner; the drainage layer should be constructed of coarse gravel and should be fitted with perforated drainage pipes made of plastic or stoneware at low points in its profile.

Italy - Liners: The following tables present examples of frequently licensed basal liners for landfill Classes 1 and 2. Three options for achieving the requirements are presented, Option 1 being based on a composite mineral/gomembrane lining system, Option 2 using a mineral liner and Option 3 relying on a twin geomembrane system sandwiching a bentonite sand layer.

Component	Option 1	Option 2	Option 3
Drainage System	Drainage layer: layer thickness 0.4-0.5m, area filter, coarse gravel. Drainage pipe HDPE or stoneware, perforated.	Drainage layer: layer thickness 0.4-0.5m, area filter, coarse gravel. Drainage pipe: HDPE or stoneware, perforated.	Drainage layer: layer thickness 0.4-0.5m, area filter, coarse gravel. Drainage pipe HDPE or stoneware, perforated.
Protective Layer	Sand, layer thickness 0.1-0.2m.	Sand, layer thickness 0.1-0.2m.	Sand, layer thickness 0.1-0.2m.
Geomembrane	HDPE, thickness 2.5mm.		HDPE, thickness 2.5mm.
Mineral/ Intermediate	Layer thickness 1m, k=1x10-8m/s.	Layer thickness not less than 2m, k=1x10-9m/s.	Sand-bentonite mix, thickness not prescribed.
Geomembrane			HDPE, thickness 2.5mm.
Subsoil	Minimum requirements do not exist, groundwater table to be no closer than 0.5m below the lower face of the mineral layer.	Minimum requirements do not exist, groundwater table to beno closer than 0.5m below the lower face of the mineral layer.	Minimum requirements do not exist, groundwater table to beno closer than 0.5m below the lower face of the mineral layer.

Table 5.7 - Italian Landfill Liner Standards

Italy - Capping: Mazzetti et al. (1991) report in great detail on the Palastreto landfill, which commenced operation in 1989. Those sections so far completed have been covered with the following capping:

Component	Required Standard
Reclamation Layer	Arable soil, layer thickness 0.5m.
Drainage Layer	Rubble, layer thickness 0.3m (also serving as root reinforcement)
Asphalt Layer	Layer thickness not less than 2mm, low porosity, sprayed on a light plastic fibre fabric.
Mineral Layer	Layer thickness 0.5m, k not more than 1x10-8m/s.

Table 5.8 - Italian Landfill Capping Standards

5.7. Japan

Background:

Japan - Liners: Gotoh (1987), Grimski (1988) and Cossu (1990) give insight into current Japanese landfill lining technology. There are 3 clearly defined landfill categories in Japan, there being an essentially different lining concept for each:

- **'Isolated Type Landfills'** accommodate wastes (primarily industrial

wastes) with concentrations of heavy metal compounds and toxic organic compounds higher than given limiting values. They are virtually covered containers, or more precisely, they consist of several container-like boxes, each of which is lined with concrete on the bottom and on all 4 sides. The concrete bottom and the external walls of boxes on the landfill perimeter must have a minimum thickness of 0.15m, and internal walls between the boxes of 0.1m. The waste is put into the container under the protection of a shelter (solidifying of the waste may first be applied), thus no leachate is generated and no drainage system is therefore required. When a box is completely filled, it will be covered with a concrete plate with a required thickness ≥0.15m. The internal walls of the containers must be protected against corrosion.

- The **'Controlled Type Landfill'** is the closest to a municipal solid waste landfill. On these landfills, municipal waste (more than 60% of it previously incinerated), and industrial and commercial wastes in which the concentration of heavy metal compounds and toxic organic compounds is below given limiting values, are deposited. For this landfill category a 'layer of low permeability material', i.e. clay soil or 'comparable', as a basal liner is compulsory. A surface-type drainage system with drainage pipes for leachate collection must be arranged on top of this. The collected leachate must be treated and completed landfill sections must be covered with a 0.5m thick layer of top soil.

- For the inert material landfill or **'Stable Type Landfill'** in which only chemically and biologically inert materials (waste glass etc.) may be deposited, no sealing measures are required.

Japan - Capping: For landfills akin to UK Municipal waste sites the requirement for covering over completed landfill sections is a 0.5m thick topsoil layer - see **"controlled type landfill"** description above.

5.8. Switzerland

Background:

Switzerland - Liners: The liner structure covered in this section is described in great detail by Fischer & Schenkel (1990) and Steffen (1992), and is based on the Technische Verordnung über Abfälle (1990), published by the Schweizerischer Bundersrat. If refers to landfill classes 'incinerator residue landfill' and 'reactor landfill' (landfills for municipal solid waste or waste with biologically degradable organic content; transitional regulation). This structure is not required for inert material landfills. The landfill classes to be discussed differ mainly in their allowable limiting values for waste eluate concentrations of COD, carbohydrates, halogenated carbohydrates, heavy metals, etc. The Schweizer Technische Verordnung über Abfälle focuses on the requirements for the barrier 'waste body' (see Stief, 1986), i.e. it contains strict requirements on the pre-treatment of waste (recycling, selection, incineration, composting, immobilisation, etc.). These requirements are reflected in low eluate limited values for the waste and thus landfill liner construction costs may be lower than in Germany. Basal liner requirements are summarised in tabulated form below:

Component	Required Standard
Drainage System	As German Standards
Geomembrane	Optional addition to the mineral layer, thickness not less than 2.5mm, intimate contact with the mineral layer is required.
Mineral Layer	Layer thickness: 0.8m, compacted in 3 lifts, K=1x10-9m/s (0.5m thick if overlaid by Geomembrane).
Asphalt Layer	An alternative to the mineral layer (+Geomembrane), layer thickness not less than 0.07m, porosity not greater than 3%, on a bituminous carrying layer.
Subsoil	Layer thickness not less than 10m, Knot greater than 1x10-7m/s.

Table 5.9 - Swiss Landfill Liner Standards

Switzerland - Capping: There are only modest requirements on the landfill capping system; "a covering" in the form of a geomembrane is sufficient. (Fischer &

Schenkel 1990).

5.9. United Kingdom

Background: Landfill liner design guidance in the UK emanates from the "Guidelines on the Use of Landfill Liners" (North West Waste Disposal Officers, Landfill Liners Sub Group, 1988). A composite design involving geomembrane and mineral layer is recommended but not mandatory. The advent of Waste Management Paper No. 26B allows the submission of designs to regulators based on risk assessment with regard to waste type, location, groundwater category etc.. Capping guidance requires a mineral sealing layer but again risk analysis is used to underpin final designs.

United Kingdom Liners: Details of "Minimum Guidance" for UK landfill liners is as tabulated below (other multi-barrier options exist):

Component	"Minimum Guidance"
Drainage System	No general requirements
Protective Layer	Sand or sand with clay content, layer thickness not less than 1m
Geomembrane	Thickness not less than 2mm, not compulsory
Mineral Layer	Layer thickness 1m, compacted in several layers, k not more than 1x10-9m/s, natural clay soil preferred
Subsoil	Low permeability material, groundwater desirable below the liner

Table 5.10 - United Kingdom Landfill Liner Guidance

United Kingdom Capping: The minimum requirement is for a mineral sealant layer with a compacted layer thickness of 1 metre, constructed in several bonded lifts. In the United Kingdom the preference is for the efficient shedding and collection of rainwater run-off. Research studies have shown above cap drainage and evapotranspiration effects to be controlling factors in long term cap performance (Bickerton, Davies & Larkin for UK DOE (1996)).

5.10. United States

Background: In the USA the landfill categories Hazardous Waste Landfill as well as Municipal Solid Waste (MSW) Landfill, also referred to as Sanitary Landfill exist. The distinguishing criteria are similar to those described for Germany, Austria, Switzerland and Japan. Strictly speaking, the liner structure described only refers to basal liners and capping systems for Hazardous Waste Landfills which in turn are subdivided into Hazardous Waste Piles (designed as a mound), Hazardous Waste Landfills (landfill in a strict sense) and Hazardous Waste Surface Impoundments (for waste fluids). Whether this same standard or another applies to municipal solid waste landfills differs from state to state; in New York State, for example, the same liner standard applies for both.

US - Liners: See tabulated minimum standards below and commentary presented overleaf

Component	Required Standard
Filter Layer	Geotextile with low unit surface weight and relatively high mesh or widely-grained mineral filter, layer thickness 0.15m.
Upper Drainage System (LCRS)	Mineral drainage layer, layer thickness 0.3m, area filter, k=1x10-2m/s, transversal slope 2%, as geonet on the slopes. Drainage pipe: HDPE, bore not less than 150mm, perforated, inspectable, long. slope 2%, centres as hydraulic design.
Protective Layer	Non-woven geotextile of high unit surface weight.
Upper Geomembrane	HDPE preferred, thickness 1.5 or 2mm, "slack" placement partially omitting intimate contact.
Bentomat	10mm thick bentonite layer (swollen), placed between two layers of non-woven geotextile frequently underlain by a 1.5mm thick HDPE membrane which prevents bentonite from penetrating the geonet.
Control Drainage System(S-LCRS)	Geonet, height of the flow cross section 5-7.5mm, mesh around 10mm, transversal slope 2%. Drainage pipes in drainage ditches with coarse gravel below the geonet level, pipe properties as LCRS.
Lower Geomembrane	HDPE preferred, thickness 1.5 or 2mm (should fit in the drainage ditch, see above).
Mineral Layer	Layer thickness 0.9mm, compacted in 6 lifts, K not greater than 1x10-9m/s, complete contact with geomembrane.
Subsoil	Low permeability (rock, clay soil), groundwater table to be always below the liner.

Table 5.11 - United States Landfill Liner Standards

There is no general federal standard for the lining of hazardous waste landfills, although the Environmental Protection Agency (EPA) requires the minimum standard in its official documentation. Each state may go beyond the US EPA standards in its own requirements but may not fall below the federal standard. The liner systems for basal liners and capping systems which follow therefore outline liner standards for densely populated, highly industrialised states such as New York. The following abbreviations are used: LCRS = (Primary) Leachate Collection and Removal System, S-LCRS = Secondary Leachate Collection and Removal System. Refer also to USEPA (1987a, 1987b, 1988a, 1988b, 1989a, 1989b, 1991), Daniel & Koerner (1991), Carra (1990).

US - Capping: A typical US capping system will comprise the following:

Component	Required Standard
Reclamation Layer	Arable soil, layer thickness 0.6m, underlain by broken rock, layer thickness 0.3m, as protection for the capping.
Filter Layer	Geotextile with low unit surface weight and a relatively high mesh or widely-grained filter, layer thickness 0.1m.
Drainage System	Sand drainage layer, layer thickness 0.3m, area filter, k not less than 1x10-4m/s, slope gradient 3-5%, or geonet
Geomembrane	Thickness not less than 0.5m, low density PE's are frequently used.
Mineral Layer	Layer thickness 0.6m, compacted in several lifts, k not more than 1x10-9m/s.
Filter Layer	Geotextile with low unit surface weight and relatively low mesh.
Regulating Layer	Gravel, layer thickness 0.3m, simultaneously used for gas drainage.

Table 5.12 - United States Landfill Capping Standards

5.11. Comparative Summary (Chaper 5 Overview)

Chapter 5 has revealed the following:

- For base liners most mainland western European countries require composite base containment with leachate drainage provision.
- Use of mineral liners in combination with geomembranes is well recorded.
- Geomembrane liner thicknesses are mandated typically in the range 2mm-2.5mm. Denmark does not mandate a requirement for a geomembrane liner reflecting the national adoption of a controlled leaching concept.

- Sand and cushion geotextiles are noted as acceptable materials for geomembrane protection layers.
- Groundwaters are almost always required to be below the subsoil support layer for which maximum permeability values are quoted. Italy allows groundwaters to be within 0.5m of the subsoil layer for Class 1 landfill - municipal solid wastes. The concept of hydraulic containment is not widely identified but some UK regeneration projects have argued successfully for this approach. (Statham, I & Treharne, G. (1998))
- No specific liner standards exist in Hungary.
- In the United States, for high population urban centres, MSW landfill liners are particularly sophisticated incorporating upper drainage layer, upper geomembrane, GCL, control drainage layer and lower geomembrane.
- UK designs for liners can be as sophisticated as the US but the number of functional elements will be determined from risk appraisal and are not simply mandated as minimum standard requirements.
- For capping systems, generally either low permeability clay layers are specified or the use of a geomembrane as an alternative is acceptable.
- Some countries such as Germany and the US mandate a composite mineral /geomembrane system.
- For cap and cover systems detailed attention needs to be paid to cap drainage and gas control. A number of geosynthetic materials or natural sands can fulfil this function.
- Capping systems in the UK do regularly incorporate sophisticated geomembrane, geotextile and geocomposite gas and water drainage products. Occasionally a composite mineral/ geomembrane capping seal will be used but again the need will be driven by detailed risk appraisal and not simply a mandated minimum standard requirement.
- The optimum design for a modern MSW landfill is now likely to comprise - **Basal Liner System:** Leachate drainage layer, geotextile cushion, geomembrane, leak detection layer, mineral liner, prepared subgrade. **Cap/Cover System:** Restoration soils, above cap drainage layer, sealing layer(s) (geomembrane and/or mineral), waste regulation/gas drainage layer.

6. CHAPTER 6 - UK SYSTEMS - QUESTIONNAIRE SURVEY

6.1. Questionnaire Design

To evaluate the subject of research, i.e. landfilling and waste management systems, a questionnaire was developed for issue to Local Waste Regulation Authorities in England and Wales. In England these were part of the County Council and in Wales they operated within City, Borough and District Councils. The questionnaire took the form of a tick box response form comprising a single A4 sheet. A further page for additional comment was provided. The questionnaire is shown at **Appendix 6**.

The main categories of enquiry were:-

- Waste Type and Design.
- Base and Capping Seals.
- Leachate and Gas.
- Future Policy.

These categories reflect the important interaction between the nature of the waste and the containment and management techniques employed to deal with the waste degradation by-products. The section on Future Policy was included to gauge the take up of higher level waste management techniques such as waste prevention, waste minimisation, recycling and waste volume reduction and pretreatment processes such as incineration, anaerobic digestion etc..

The questionnaire was compiled using the File Maker Pro/Claris Works database software. This enabled questions and data to be presented in a clear graphical format. Large numbers of records can then be quickly reviewed to assess data trends and percentage responses. Questionnaire forms are easily reproducible with the check box data entries readily viewed for instant feedback.

Landfills were selected using the Aspinwall Site File Digest (1993). The Site File records are contained within a database developed by Aspinwall for the Department

of Environment. The records contain data on Landfill Operator, Landfill Name, Landfill Location (**N**ational **G**rid **R**eference), Waste Regulation Authority, Waste Categories, Waste Disposal (Management) Licence reference etc.. In selecting a sample of landfills for questionnaire issue the area of study was limited to England and Wales with **3-Star (***)** and **4-Star (****)** category landfills targeted and further refined to those licences which included the **(H)** or household waste category. These were adjudged to be representative of municipal solid waste disposal facilities.

Pilot Issue: In March 1994 a 'pilot' issue of six questionnaires was distributed to test the appropriateness of the questionnaire layout. The responses indicated that the form logic was understandable and the minor amendments made were focused on better presentation and the addition of further questions in order to elicit all the desired information. Responses and final form layout were discussed with the project supervisors.

Within the main topic headings tick (or check) box options were presented with respect to waste categories such as (inert, municipal, difficult, special) etc., void space, landfill design (containment or otherwise). Further options were provided to define basal seal types, capping types and whether low grade materials such as colliery spoil, china clay wastes, etc. were used in their construction. The important aspects of leachate and gas management were included with questions on leachate disposal, leachate pre-treatment, gas flare, gas to energy systems. Details of incidents of leachate and gas escape were included.

In recognition of the fact that landfill in itself is unlikely to be sustainable as void resources are depleted the move to total or integrated waste management systems was recognised. Accordingly, questions on waste prevention, waste minimisation, recycling and forms of waste transformation or pretreatment such as incineration and anaerobic digestion were included in the questionnaire.

6.2. Questionnaire Distribution

A total of 444 landfills were selected for release of the questionnaire. Issue date was the mid 1990's following introduction of the Waste Management Licensing

Regulations (1994).

Records have been compiled from questionnaire returns from the following authorities:-

AUTHORITY	AUTHORITY
Alyn & Deeside District Council	Lancashire County Council
Arfon Borough Council	Leicestershire County Council
Avon County Council	Lincolnshire County Council
Bedfordshire County Council	London Waste Regulation Authority
Berkshire County Council	Merseyside Waste Disposal Authority
Blaenau Gwent Borough Council	Merthyr Tydfil Borough Council
Buckinghamshire County Council	Montgomery District Council
Cambridgeshire County Council	Neath Borough Council
Cardiff City Council	Newport Borough Council
Carmarthen District Council	Norfolk County Council
Ceridigion District Council	North Yorkshire County Council
Cheshire County Council	Northamptonshire County Council
Cleveland County Council	Northumberland County Council
Colwyn Borough Council	Nottinghamshire County Council
Cornwall County Council	Ogwr Borough Council
Cumbria County Council	Oxfordshire County Council
Cynon Valley Borough Council	Preseli Pembrokeshire District Council
Derbyshire County Council	Radnor District Council
Devon County Council	Radnor District Council
Dinefwr Borough Council	Rhondda Borough Council
Dorset County Council	Rhymney Valley District Council
Durham County Council	Shropshire County Council
Dwyfor District Council	Somerset County Council
East Sussex County Council	South Yorkshire County Council
Essex County Council	Staffordshire County Council
Gloucestershire County Council	Suffolk County Council
Glyndwr District Council	Surrey County Council
Greater Manchester WDA	Swansea City Council
Hampshire County Council	Tyne & Wear
Hereford & Worcestershire C. C.	Warwickshire County Council
Hertfordshire County Council	West Sussex County Council
Humberside County Council	West Yorkshire JWMD
Isle of Wight	Wiltshire County Council
Islwyn Borough Council	Wrexham Maelor Borough Council
Kent County Council	Ynys Mon Borough Council

Some authorities did not return full data sets, with some indicating that the Department of Environment was undertaking a similar data gathering exercise for the generation of a national GIS based data retrieval system for landfills. The D.o.E. had commissioned teams of engineering consultants thus reflecting the scale of the task and recognising the Local Waste Regulation Authorities difficulties in responding considering their regulatory workload.

Analysis of the 'positive' responses indicated that data (albeit in some cases incomplete) had been provided for some 185 of the 444 landfills - a return of 42%. In postal questionnaire studies this response can be regarded as good. Nevertheless, further attempts were made to improve on the result. Landfills for which there was either no response or a negative response from the LWRAs were again targeted this time via the landfill operators. Data on a further 133 landfills were obtained in this way bringing the overall 'success' rate for the questionnaire to just over 70% - an excellent result. It should be noted, however that not all questions were answered on the returned questionnaires leading to high "Nil Data" returns for a number of questions.

Enquiries were also made at the Department of the Environment to see if further data could be obtained from their GIS database. This initiative was, however, not complete and the DoE were unable to assist. It is interesting to note that the DoE questionnaire ran to some 13 pages (not tick box) whereas in the current survey many of these question topics have been covered in a single A4 sheet with a tick box format. The DoE questionnaire is mounted on Microsoft's Access database software.

6.3. Response and Analysis

From the questionnaire returns the following data have been obtained (listed here under the appropriate category heading). Refer to Appendix 7 for detailed listing.

Question 1: Licence Valid Post May 1994?: Of the 444 forms issued this section yielded a "yes" response of 218 (49.1%), "no" 100 (22.5%) and a nil data response

of 126 (28.4%). The data are presented in Figure 6.1.

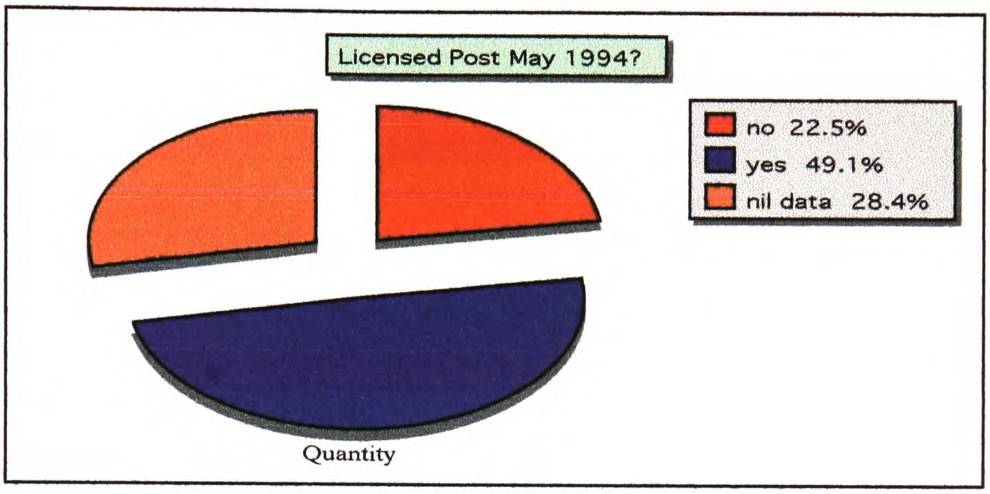

Figure 6.1: Licences Valid Post May 1994

The response demonstrates clearly that a significant number of the landfill sites canvassed were intending to continue operations under the new Waste Management Licensing Regulations 1994 even with the more onerous provisions for site design, operation, monitoring, closure and aftercare. This must be seen as a plus for environmental protection as these sites will be rigorously monitored and regulated. The smaller number of sites recorded as not continuing under the new regulations does however represent a significant legacy. These sites were able to surrender their licences under a more lenient regime and have the potential to cause future environmental harm but without the benefit of any financial provision having been made by the operator for possible remediation measures. Many of the "nil data" sites are now omitted from the later issue of SiteFile Digest (post 1994) and are likely to have ceased tipping with the advent of the new waste licensing regulations.

Question 2: Waste Type?: Analysis of the questionnaire data shows that 149 sites (21.5%) accepted inert wastes, 215 sites (31%) municipal wastes (household, commercial and general industrial), 61 sites (8.8%) special wastes and 2 sites (registered as 0.3%) burnt residues (from municipal waste incinerators). A figure of 58 sites (8.4%) were registered as operating a co-disposal operation. This percentage closely mirrors the response on special waste. Some 2.2% (15 sites.) of returns indicated an "alternative" waste type, this was generally separate clarification

of acceptance of commercial and industrial waste which is often commonly included under the cover-all municipal waste terminology. A "nil data" return was registered for 192(27.7%) of the released questionnaires. The data are presented in Figure 6.2.

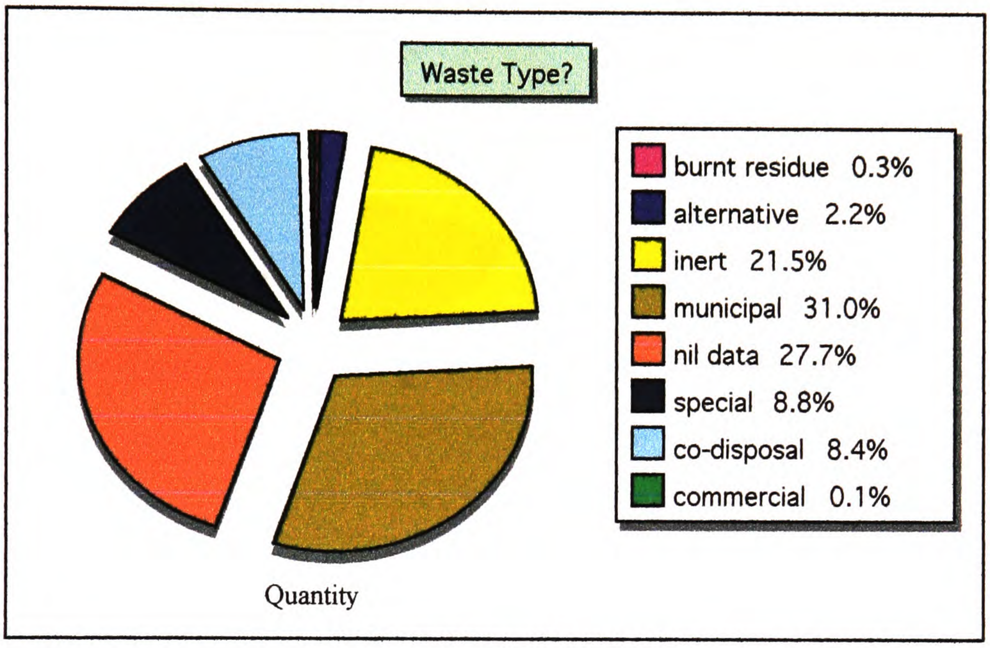

Figure 6.2: Waste Types

With regard to the significant percentage of sites accepting inert wastes these are generally combined with municipal and other wastes (i.e. within the multiple choice responses) and this seems to indicate clearly the use of inert soil as a daily cover material at municipal waste sites. The high response to the "municipal" option underpins the selection of "3-star" and "4-star" (including "H" for household classification) category landfills from the "Sitefile" database of landfills.

Question 3: Void Space?: For the 444 questionnaires issued 87 sites (31%) had a void space less than 1 million m^3, 42 sites (16%) in the range 1 - 2 million, 44 sites (16%) in the range 2 - 5 million, only 10 sites (4%) in the range 5 - 10 million and, 8 sites (3%) having a void space greater than 10 million m^3. A significant non return figure of 257 sites (57.4%) is registered as a "nil data" return. This suggests that they had no information on site volume or perhaps that this information is considered commercially valuable and therefore not suitable for disclosure. The data are presented in Figure 6.3 overleaf

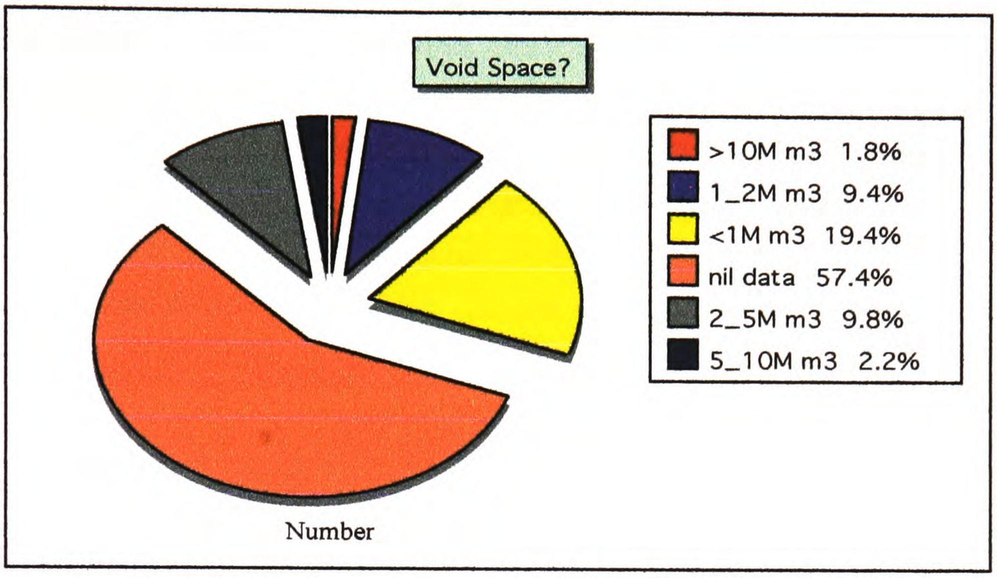

Figure 6.3: Void Space

Depending on waste types a correlation between void space and the application of containment techniques can be considered. With the expenditure required for containment and management systems, only sites of significant void capacity (say, greater than 2 Million m^3) are likely to be able to sustain the high "engineering" budgets required. All returns registering void space greater than 10 Million m^3 recorded containment as the design concept. Similarly the containment principle was embraced for the majority of landfills for which data returns were received in the void space range 5-10 Million m^3 . For sites of 2-5 Million m^3 void about 75% adopted containment principles. The picture is similar for sites of void space 1-2 Million m^3 capacity. This percentage reduced to about 50% for sites of less than 1Million m^3. Site location and available clay resources will, however, influence site development costs and sites with locally available clays and having void space less than 2 million m^3 may well be able to sustain the cost of engineering containment. It is interesting to note that the combined percentage of sites in the range 2 - 10+ million m^3 void space equates to nearly a quarter of the sites for which data were obtained. There are thus clear indications that larger regional facilities are now being developed, capable of sustaining full engineering containment measures.

Question 4: Design Concept?: The spread of data for the 444 questionnaires issued shows that 90 sites (12%) involved an element of land raise (development above general surrounding ground level). Development within a mineral void took place at 144 sites (19.3%), with cellular filling recorded at 85 sites (11.4%). A high number of sites, 141 (18.9%), registered containment as the basis of design with 84 sites (11.2%) identifying "dilute and disperse" as the design concept. "Nil data" returns were registered for 193 sites (25.8%). The data are presented in Figure 6.4.

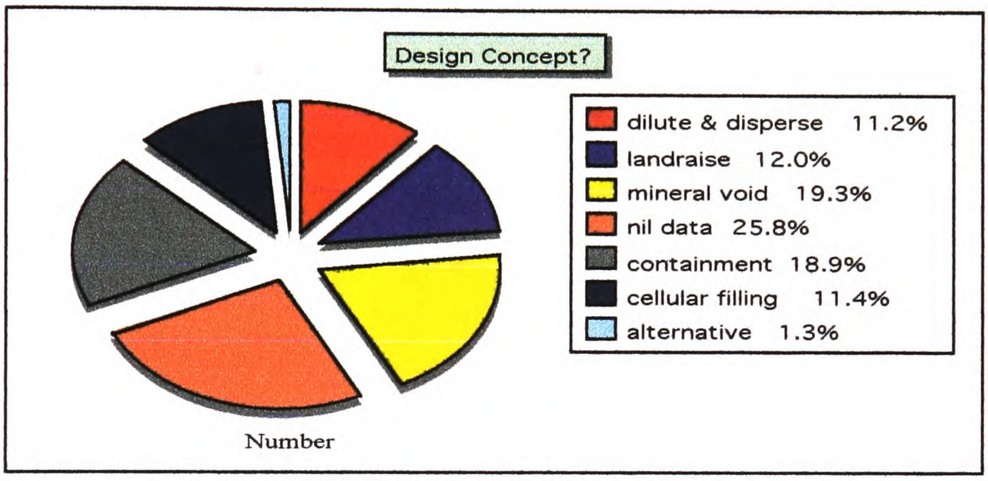

Figure 6.4:

Of interest in the above data is the match between engineering containment and developments within mineral voids. Where waste is placed within the local geology the potential for groundwater contamination may be considered highest, although the concept of hydraulic containment by the surrounding groundwater table is finding favour as a design argument. The mechanism of molecular diffusion then has to be considered carefully. A significant proportion of sites record "dilute and disperse" as the operating concept - this is likely to reflect the transition period between the older design concepts and uptake of the new containment philosophies.

Question 5: Basal Seal?: The questionnaires analysed show that 78 sites (17.8%) have no basal seal containment - this correlates almost exactly with the 82 sites recording "dilute and disperse" as the design concept. Only 13 sites (3%) recorded the sole use of a synthetic liner as the basal sealing layer. This must be considered alongside the 27 sites (6.2%) that returned a data choice of a composite basal seal

(most likely clay with synthetic). In total, therefore, about 40 sites (9%) identified a synthetic liner as part of their basal seal system. A mineral (clay) basal seal was recorded for 113 sites (25.7%) as the sole lining element but adding the further 27 sites using a composite clay / synthetic system, this increases the sites utilising clay seals to 140 (32%). A bentonite mat was recorded as being used in the basal seal of only 3 sites (0.7%), with bentonite enhanced soils used for 8 sites (1.8%) and reconditioned natural soils used for 5 sites only (1.1%). The "nil data" for this section amounted to some 189 sites (43.1%). The data are presented in Figure 6.5.

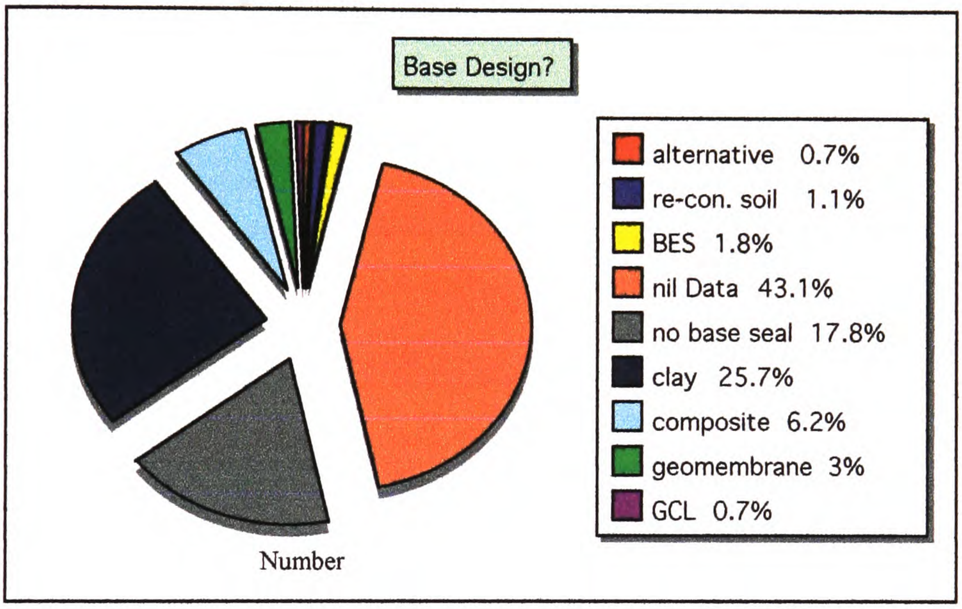

Figure 6.5: Base Design

From the returns it is clear that the predominant sealing material for the sites canvassed in England and Wales is clay. This may well reflect the local availability of clay materials in the areas where landfill development is taking place. It also reflects the long history within the UK of using clays as an engineering material and the construction industry's (and also perhaps the regulators') sense of security and understanding in using a more traditional and well established earthworks material. Also the process of placement uses plant and machinery that is proven and well understood by contractors. The relatively small incidence of synthetic materials utilisation is perhaps surprising given the promotion given to plastic liners, driven

from experiences in the US and continental Europe. Although the number of sites using synthetic basal sealing elements is small the trend is likely to be on the increase as the regulators' preference is towards composite systems using both clay and synthetic layers. The thickness afforded by the clay layer provides for separation of the synthetic geomembrane from the wastes and clay layers are also known to have good properties of filtration, or cleansing, with respect to the passage of many toxic substances. A US study has investigated the technical equivalency of CCLs and GCLs. It concludes that it is expected that GCLs can be shown to provide better or equivalent performance at many sites. (Koerner, R., Daniel, D. (1994)) *With regard to use of CCLs in the US a study by Fahim & Koerner in 1993 showed that CCLs were used as single liners in 19 states, in composite liners beneath a geomembrane in 20 states, as a single cover(cap) in 36 states and as a composite cover beneath a geomembrane in 6 states. In liners the use of clay in composite systems outweighed the single use of clay, but in caps use of the single clay layer outweighed the use of clay in composite caps.*

Question 6: Capping Layer: Some 42 sites (9.4%) of the 444 questionnaires recorded that no formal cap was in place. This indicates that ordinary soil cover with no low permeability component is being used. There were 25 sites (5.6%) which recorded synthetic caps and about 16 sites (3.6%) composite caps. The number of sites using synthetic geomembranes either as the sole capping layer or as a component of the cap is, therefore, 41 (about 9%). Bentonite mat systems were identified for only 3 sites (0.65%), BES for 3 sites (0.65%), and reconditioned natural soils for just over 26 sites (5.8%). Again the predominant material used as the sole capping element was clay accounting for some 141 sites (31.5%). Combining this with the clays used in composite systems the number of sites employing engineered low permeability clays was 157 (58%). The "nil data" response accounted for about 189 sites (42.2%) which is identical to the "no data" response for the questionnaire section dealing with basal seal systems. It is also close to the combined "no" and "nil data" responses recorded for sites planning to continue operations after May 1994. The data are presented in figure 6.6 overleaf.

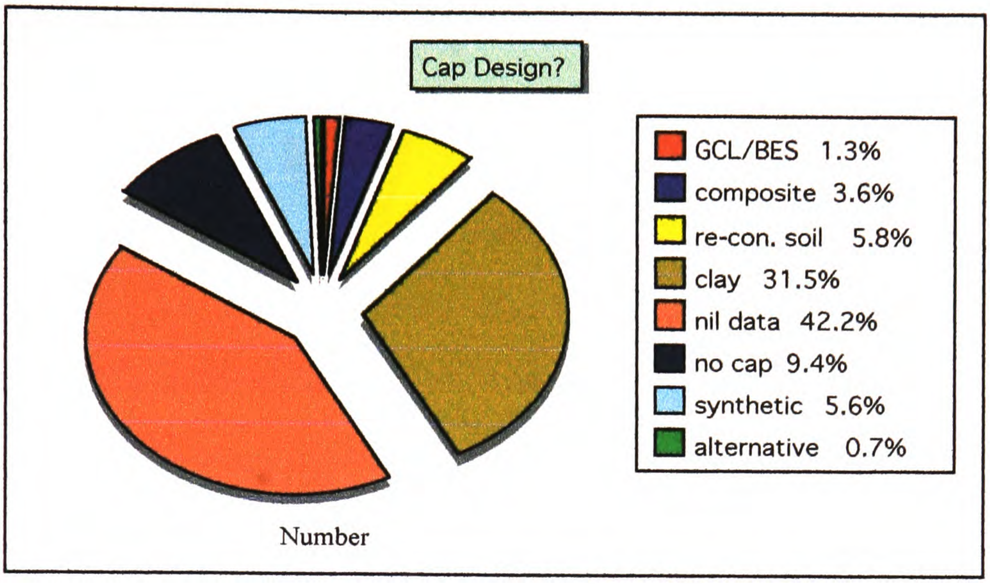

Figure 6.6: Cap Design

From the data responses on capping types the dependence on clay materials is again strongly evident. The low permeability clay placement specification for landfills issued by the National Rivers Authority (North West Group) in 1989 may have much to do with this as it conferred a certain "seal of approval". In addition the same "comfort factor" in using a traditional engineering soil allied with local availability at many sites is a strong influential factor in respect of landfill caps as for basal seals. The presence of earthworks plant at many landfill sites may also influence selection as operator resources can be optimised in the construction process.

Question 7: Low Grade Waste Used?: The responses received to this question were "no" 197 sites (43.9%), "in base system" 15 sites (3.3%) and, "in cap system" 23 sites (5.1%). There was a "nil data" response of 47.7% (214 sites) for this question. The data are presented in figure 6.7 overleaf.

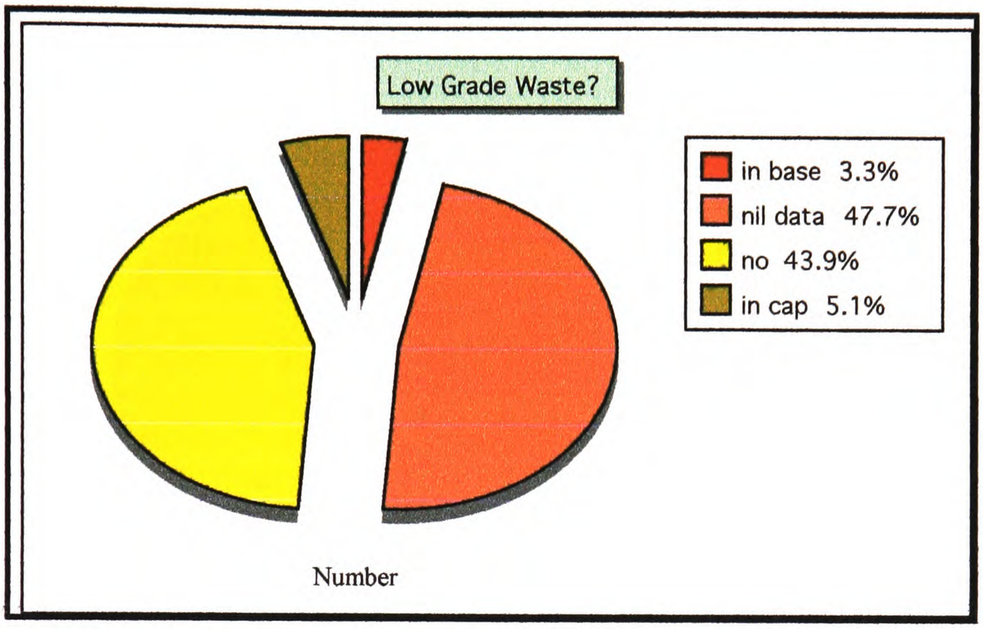

Figure 6.7: Low Grade Waste Use

In terms of the DOE's complementary strategy for the reuse of construction and demolition wastes in new engineering projects this response has to be seen as somewhat disappointing. Apart from isolated instances there seems to be a complete disinterest in using these materials in landfill base and capping systems. One explanation is that the questionnaire layout posed some confusion for respondents to this question. However, the types of material being considered are identified in the questions that followed so confusion should have been avoided. Perhaps the regulatory pressure on the need for high CQA standards and build quality are having an impact on the ready take-up of these materials.

Question 8: If Base, Which Waste?: In total only some 6% of the group of sites for which data has been analysed used low grade "waste" materials in the base sealing system. This was either as a support, sealing or protection layer. The spread of usage was "colliery shale" 2.3% (10 sites), china clay waste near 0.2% at 1 site only, with overburden waste 3 sites (0.7%) There was no usage of gravel washery silts in basal systems. The "nil data" response of 95% closely mirrors the combined "no" and "nil data" responses recorded under question 7. The data are presented in Figure 6.8 overleaf.

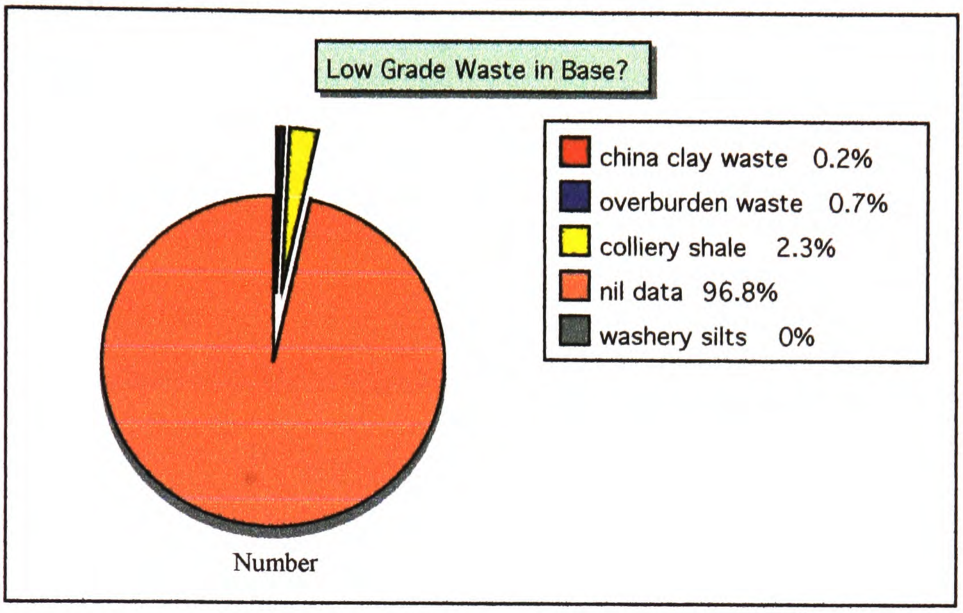

Figure 6.8: Low Grade Waste Use In Base

The resounding message is that construction and demolition wastes are not being as fully utilised as they could be. Thus useful secondary materials are being under utilised and are most likely being confined to the waste body proper.

Question 9: If Cap, Which Waste?: The results from this question show again a very low take up of secondary material usage with only 8% of sites employing these materials. The data are presented in Figure 6.9 below.

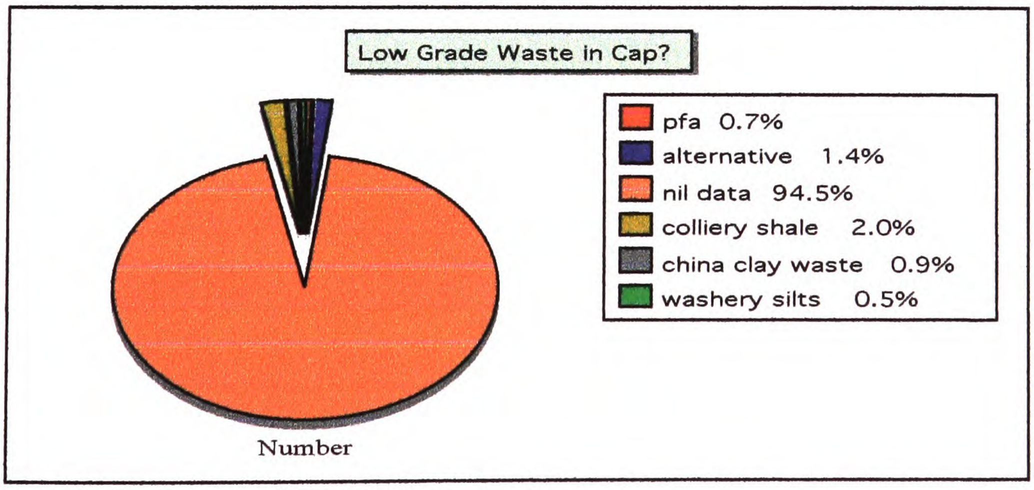

Figure 6.9: Low Grade Waste Use In Cap

In similar measure of use are PFA 3 sites(0.7%), china clay waste 4 sites (0.9%) and gravel washery silts at 2 sites(0.5%).Colliery shale has the greatest recorded usage at 9 sites (2%).The majority of questionnaires 416 (94.5%) returned a "nil data" response roughly equivalent to the combined "no" and "nil data" responses under question 7.

Again a clear message is being sent. This is that low grade secondary materials are not being utilised in base or capping systems. This could have something to do with the regulatory insistence on the development of ever tougher specifications with the focus on high grade materials leaving little option for the consideration of lower grade although nonetheless perfectly appropriate materials? It is interesting to note that studies into the use of fly ash materials as impermeable barriers have concluded that these materials can produce a lining/capping structure with the requisite low permeability value specified by regulators. Beneficial effects such as the precipitation of heavy metals from waste leachates within the fly ash layer have also been recorded. (Edil, T.B., et al (1992)) & (Bowders, J.J., et al Energy Research Centre)

Question 10: Leachate Management?: A recorded 73 sites (14%) of the questionnaire release recorded no leachate management system. This matches closely with the figure of 82 sites which returned a "dilute and disperse" response under Question 4 - Design Concept. Disposal of leachate to public sewer is recorded at 44 sites (8.4%), 32 sites (6.1%) discharged leachate to waterways via a consented outfall, 56 sites (10.7%) employed tanker collection, 68 sites (13%) operated leachate recirculation systems and 47 sites (9%) had on-site treatment facilities. The level of "nil data" response was 198 sites (37.9%). The data are presented in Figure 6.10 overleaf.

The total number of records for this question is 351 reflecting the multiple choice responses available on the questionnaire. It can be deduced from this that a number of sites may operate a number of options, within different phases of landfilling, such as leachate recirculation combined with on-site treatment prior to either public sewer or consented discharge or perhaps tanker collection.

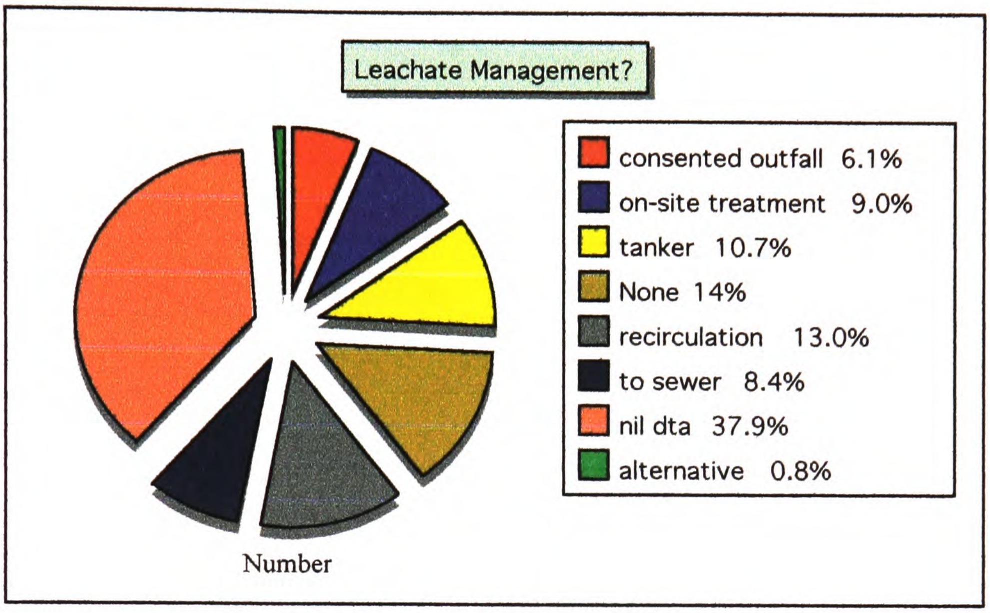

Figure 6.10: Leachate Management

The number of sites served by tanker collection is a significant percentage and this must add greatly to the costs of landfilling where public sewer or consented outfalls are not available. In these instances greater reliance will be placed on efficient water balance design and exclusion of rainwater ingress with the phased provision of efficient low permeability "intermediate"cap systems. This lack of "flushing" will compromise waste degradation, however, leading to longer periods before waste stabilisation can be accomplished. Combining leachate management with waste pre-treatment processes would, however, be a more sustainable approach.

Question 11: Gas Management?: For this question forty five sites (14%) had no gas management system, with gas venting to atmosphere directly through the cover soils. This matches fairly closely with the number of sites recording "no cap" under Question 6. The sites employing passive venting systems numbered some 122 (24.5%), with active flaring or supply to process furnaces (at brickworks etc.) recorded at 88 sites (17.7%). Gas extraction with energy recovery was in place at 39 sites(7.8%) - combined with sites supplying brickwork furnaces etc. utilisation of gas from the survey closely mirrors the figure in "Waste Strategy 2000". The level of "nil data" returns was 198 (39.8%). These data are presented in Figure 6.11

below.

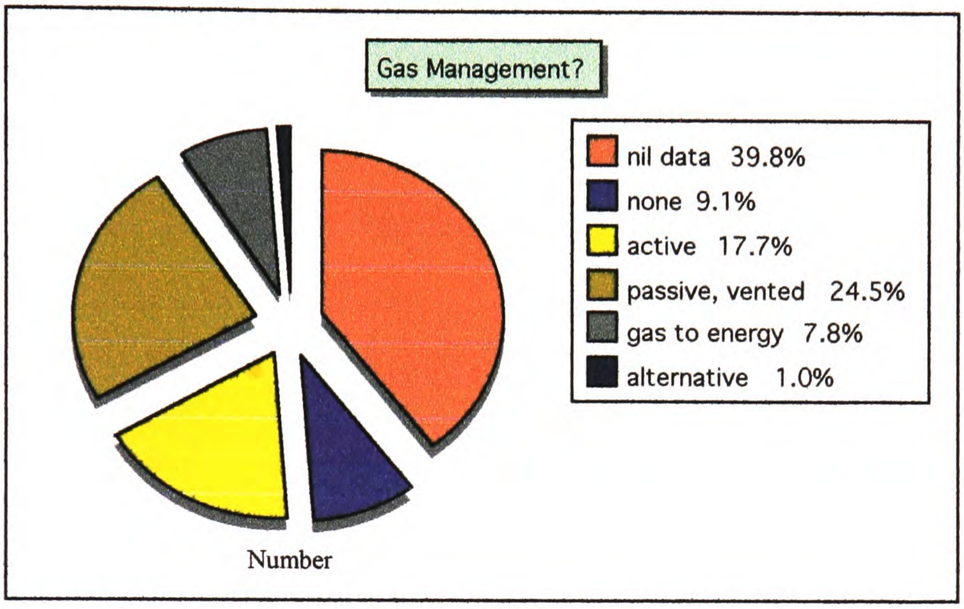

Figure 6.11: Landfill Gas

Again the multiple choice responses exceeded the number of landfills in the group being analysed. This is explained by certain sites having different phases of development, some older phases of which may have perhaps no gas management, some intermediate phases having passive venting with more modern phases combining gas extraction and flaring with energy recovery. The majority of sites have either passively vented systems or active venting systems with final flaring to burn off methane. The percentage of sites having gas to energy systems reflects the encouragement offered by the non fossil fuel obligation (NFFO) grants currently available. Even without grant aid it is likely that the number of gas to energy schemes will continue to increase as they are seen as commercially viable in their own right. At the time of the survey only 10-15% of sites utilised energy recovery from landfill gas. A vast potential resource is therefore being under-utilised. Sustainability of gas management systems is likely to improve with the progression towards fewer but larger regionally centred landfills. Gas energy can also still be utilised in conjunction with waste pre-treatment processes - again likely to be included within significant regional waste centres.

Question 12: System Failures?: The responses to this question gave an "often" response of 8 sites(1.8%), "occasional" 92 sites (20.9%), "never" 96 sites (21.8%). The level of "nil data" returns was 245 sites(55.6%). The data are presented in Figure 6.12.

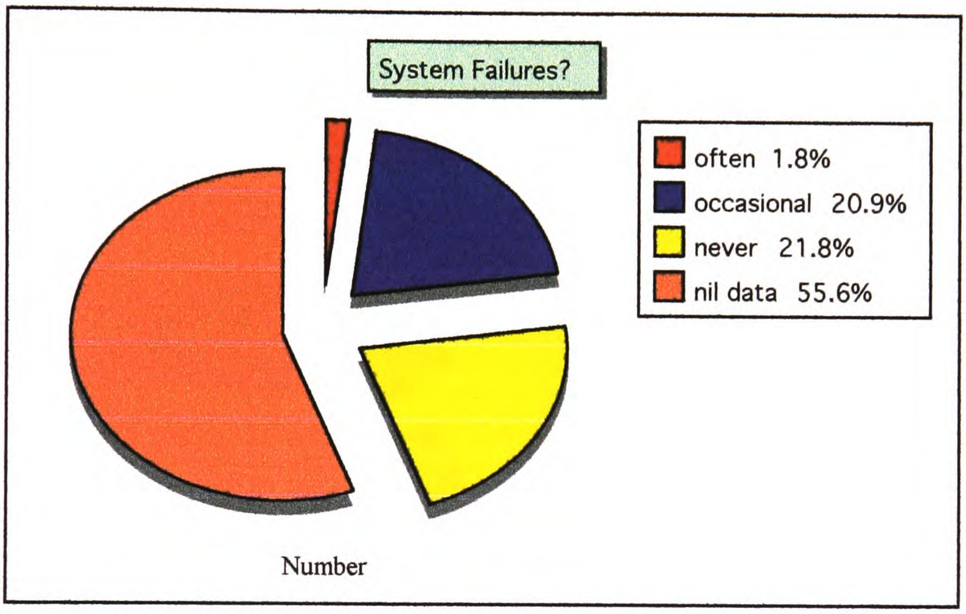

Figure 6.12: System Failure Events

A high level of nil data returns was received for this question. This almost certainly reflects the sensitivity of this information. No-one likes to own up to failing systems, especially in the context of projects impacting on the environment. It is interesting that the total number of sites registering system failures of varying frequencies is 100. This is nearly a quarter of the sites investigated. This is a significant number and the honesty of these responses is to be applauded. Nonetheless, the sensitivity of the data coupled with the high number of nil returns suggest that the actual number of instances of system failures is likely to be very much higher than this. The seriousness of these failures will be under review by the Environment Agency through regular site checks. Failures, however, need not necessarily convert to pollutant escapes and this is investigated in more detail in the follow on questions below.

Question 13: If Yes, Which System?: The significant factor in response to this question is again the high level of "nil data" returns, some 245 sites (72.1%). This matches exactly the "nil data" response to question 12 on system failures?. Of the positive responses to this question there is roughly equal distribution between leachate system failures (48 sites, 14.1%) and gas system failures (41 sites, 12.1%). The number of base and cap failures is recorded at a much lower level, at 3 each (about 1%). The data are presented in Figure 6.13.

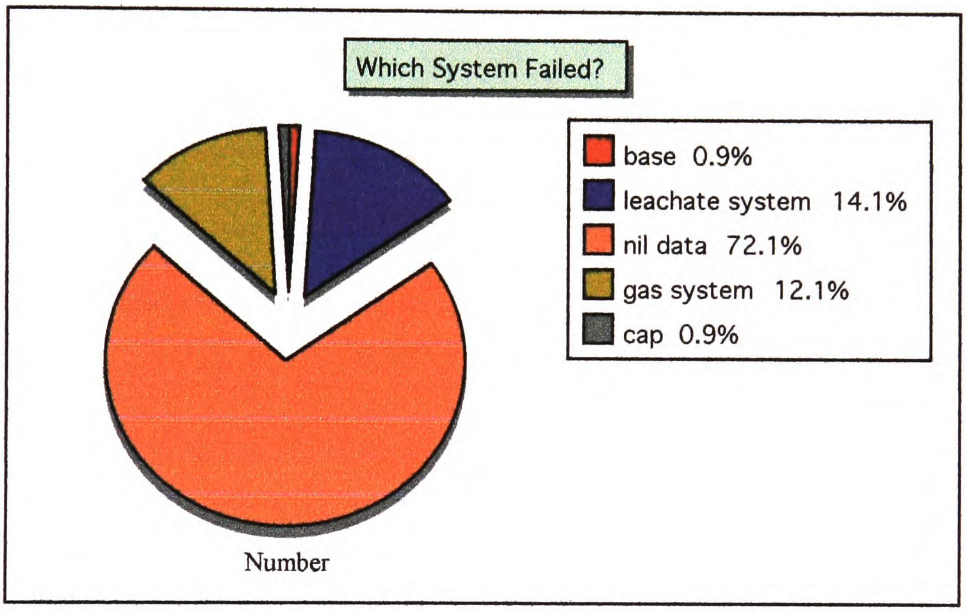

Figure 6.13: System Failure Elements

This may engender confidence in the effectiveness of base and capping systems or may indicate that potential failures of these elements are being attributed to or described as failures in either leachate / gas pumping and control systems. There is a possibility that rather than mechanical failures in these control systems the flaws may be more deep seated and more difficult or impossible to eradicate. For example, failures in the containment seals themselves. This in turn could lead to greater reliance and service loading being placed on the mechanical management systems dealing with leachate and gas. However, under these more intensive operating conditions they themselves will become more prone to failure or breakdown and require more intensive maintenance or remedial action plans.

Question 14: Pollutant Migration?: Some 85 (19.3%) of sites recorded pollutant migration. A "no" response was recorded for 92 sites (20.9%), whilst 16 sites (3.6%) returned a "maybe" response to the question. "Nil data" responses were returned for 247 sites(56.1%). The data are presented in Figure 6.14.

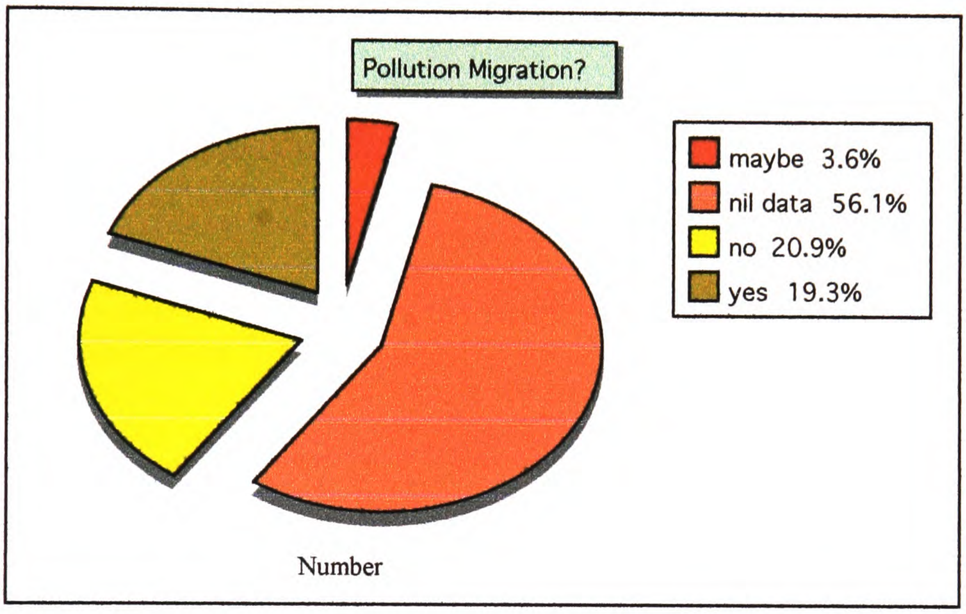

Figure 6.14: Pollution Migration Events

A significant response of nearly 20% for confirmed pollution migration gives cause for concern. The additional response of about 4% which recognises that pollution migration may be occurring is also cause for concern. From this almost a quarter of sites are citing concerns over pollutant migration - a significant proportion. However, it is also heartening to note the positive record of sites confirming no pollution migration, just over 20%. This proves the case that landfills, with proper management and environmental controls, can operate without causing nuisance. The aim must be to ensure that all landfill sites operate to this high standard. The "Nil data" response closely mirrors the figure recorded for Question 12.

Question 15: If Yes, Which Pollutant?: Leachate escape was recorded at 63 sites(13.2%), and gas escape at 68 sites (14.3%). The level of "nil data" returns were 346 (72.5%) of questionnaires. The data are presented in Figure 6.15 overleaf.

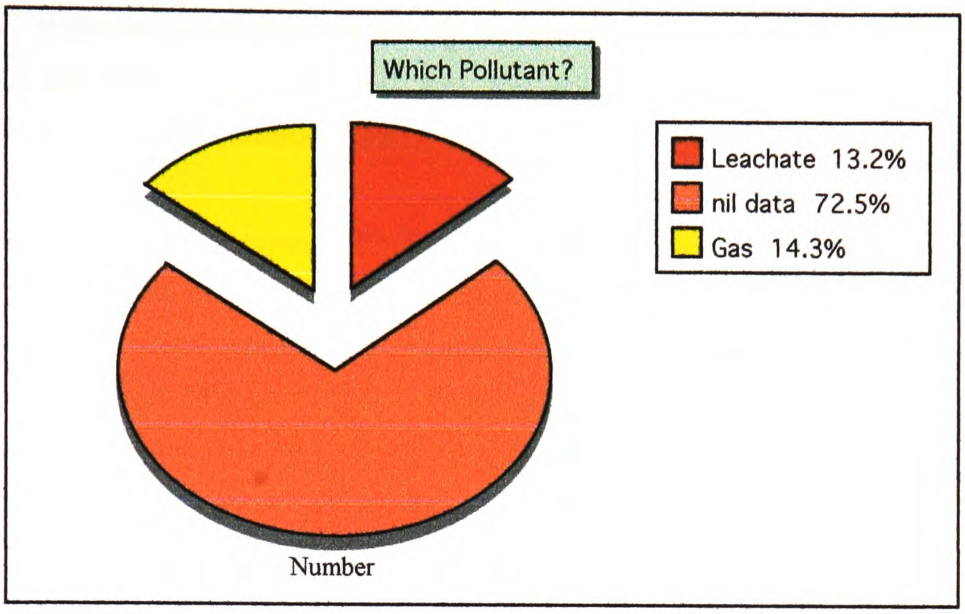

Figure 6.15: Pollution Type

The level of leachate and landfill gas escapes are essentially recorded in equal number, around 15% for each. "Nil data" responses for this question reflect closely the level of "never" and "nil data" returns for Question 12.

Question 16: Failure Retrievable?: Refer to the data presented in figure 6.16.

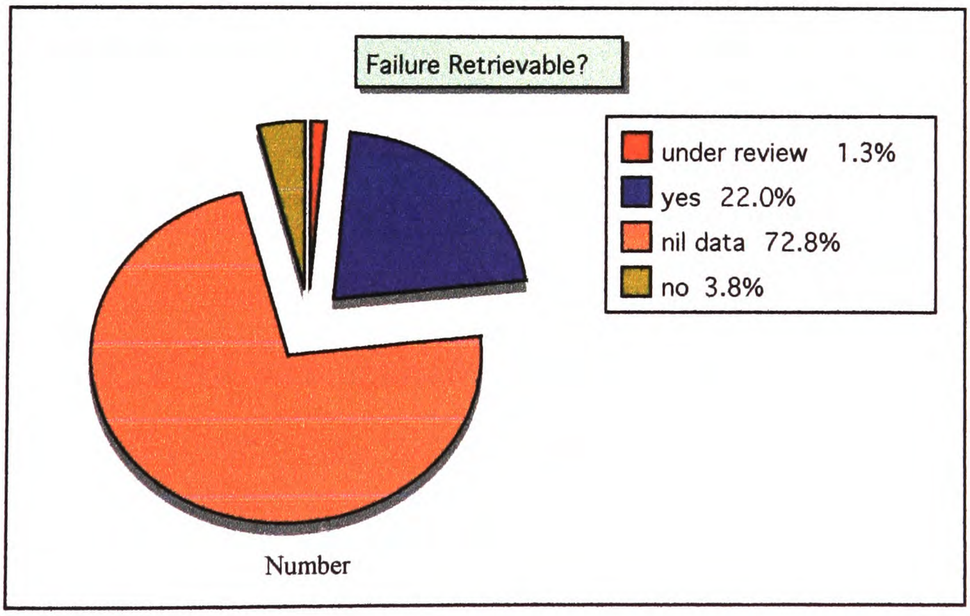

Figure 6.16: System Failure Rectification

"Yes" responses were recorded for 98 (22%) sites, with a "no" response of 17 (3.8%) sites. Six sites (1.3%) recorded "under review", and there was "nil data" from 324 (72.8%) of questionnaires.

The optimistic "yes" response for 22% of the sites to the ability to retrieve system failures is heartening. This would appear to suggest that the failure difficulties are operational in nature and not inherent to bad design or construction. It is likely that the failures relate more to the level of inspection and maintenance in respect of the mechanical leachate and gas management systems. "Nil data" responses for this question reflect closely the level of "never" and "nil data" returns for Question 12.

Question 17: Pollution Contained?: Again, for this question a high degree of "nil data" was returned, some 309 sites (69.1%) similar to question 12. Containment of pollutant migration was confirmed at 103 (23%) sites. Non-containment was recorded for 21 (4.7%) of sites and, "under review" status at 14(3.1%) of the sites. The data are presented in figure 6.17.

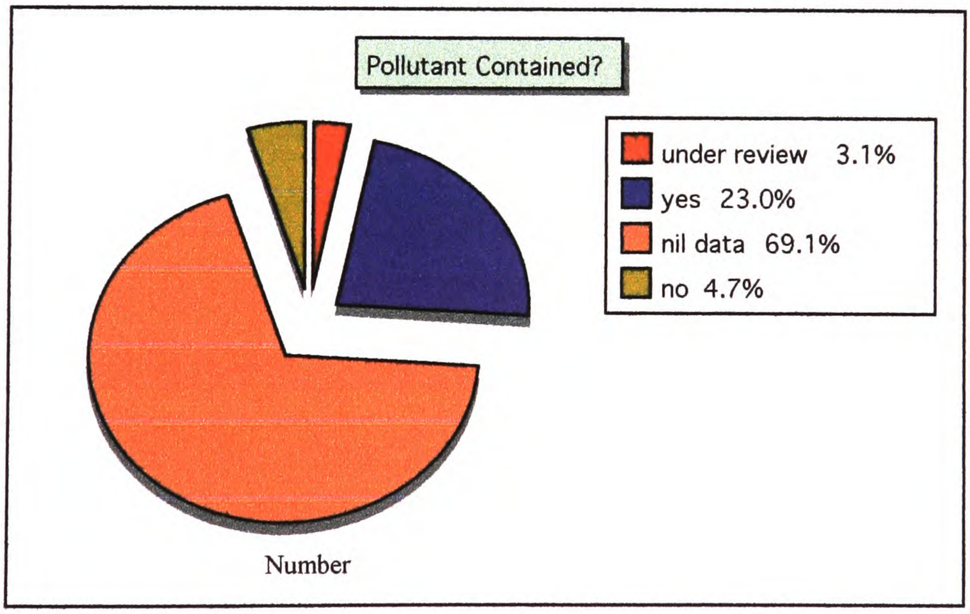

Figure 6.17: Pollution Contained ?

The level of sites confirming that pollution incidents could be containe, and are not a

constant condition matches almost exactly with the level of response for confirmed retrieval of system failures. This confident response is in a ratio of about 5:1 to the level of "no" response to the aspect of pollution containment. A significant "nil data" response of nearly 70% can contain some worrying trends and this would be worthy of further investigation. The level of "nil data" and "under review" responses mirrors closely the level of "never" and "nil data" returns for Question 12 - System Failures.

Question 18: Tipping Life, Post 1995?: From the data it is apparent that 92 sites (19.2%) would exhaust void space by the end of 1995, with a further 33(6.9%) having used up the available void space by the end of 1997. By the year 2000 a further 55 (11.5%) of sites will have run out of tipping space. By the year 2005 a further 39 (8.1%) sites will need to be replaced. At the time of survey only 42 (8.8%) sites were projected to have an operational life extending beyond the year 2005. A "Nil data" return was recorded for 214(44.6%) questionnaires. The data are presented in Figure 6.18.

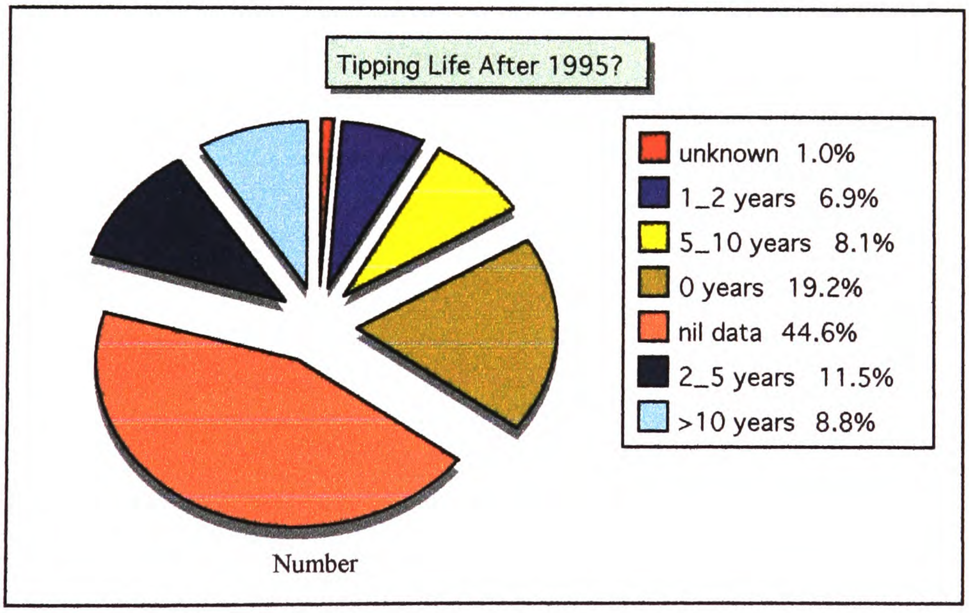

Figure 6.18: Tipping Life

From the data returns some 50% of the sites surveyed will have completed filling by

2005. Taking a void space of $1Mm^3$ for each of these sites a substitute volume of over $200Mm^3$ will need to be found. This is considered a conservative estimate as the average volume of each of the sites being considered is likely to be greater than $1Mm^3$. Without a radical change in waste management in the United Kingdom this turnover of void space will not be sustainable. Waste volume reduction techniques including recycling, recovery and pre-treatment will have to be developed in greater number to lower the volume of waste residues for disposal.

Question 19: Future Policy?: In this category a good mix of responses has been received - many being multiple options demonstrating that authorities/operators were preparing to embrace the integrated waste management philosophy as of 1995. Waste pre-treatment such as digestion was being considered in 19(2.4%) returns, incineration in 42(5.3%) returns and composting in 62(7.8%) returns. Waste minimisation was being considered in 73(9.2%) returns, waste recycling in 116(14.6%) returns and waste transfer in 55(6.9%) returns. The final disposal option of landfill was indicated in 184(23.2%) returns. A "Nil data" response of some 240(30.3%) returns was recorded. The data are presented in Figure 6.19 .

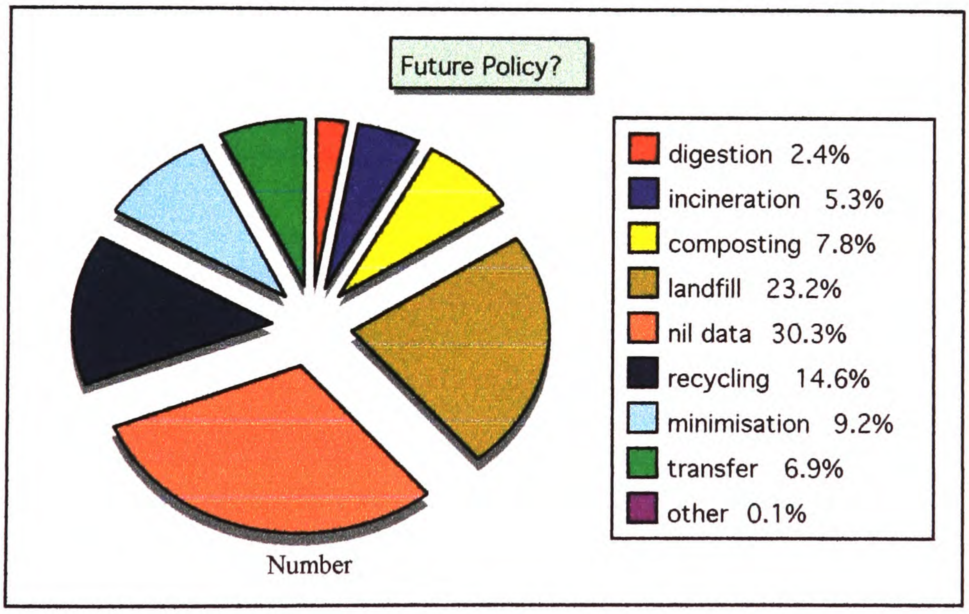

Figure 6.19: Future ISWM Strategy

As if in recognition of the unsustainable demand for ever increasing void space that a landfill reliant programme requires, the survey response represents a sea change

in attitude emerging in the United Kingdom by the mid 1990's. Although landfill remains an important element of many authorities'/operators' strategy it is now supported by options such as incineration, recycling, composting, digestion etc..This was at a time when UK DoE were strongly advocating bioreactor landfill technology. It appears that far from heeding domestic guidance, for which the waste industry was to provide the research options on a large scale, practitioners were already looking to continental Europe where pretreatment of wastes had been successfully implemented and the technologies refined over about 20 years. Many UK waste firms have European parent companies and this may well be the driving force. In addition UK companies need to develop systems which can be used in the export markets of the world, including continental Europe. The bioreactor landfill is not going to sell well there.

Question 20: If Landfill, Design Preference?: Under this question the significant data response was for containment landfill - some 195(41.9%) returns. Dilute and disperse landfill design choice was minor in comparison accounting for only 17(3.7%) returns. Likewise the future choice of co-disposal landfill was minor with only 22(4.7%) returns. A "Nil data" response of 231(49.7%) was recorded. The data are presented in Figure 6.20.

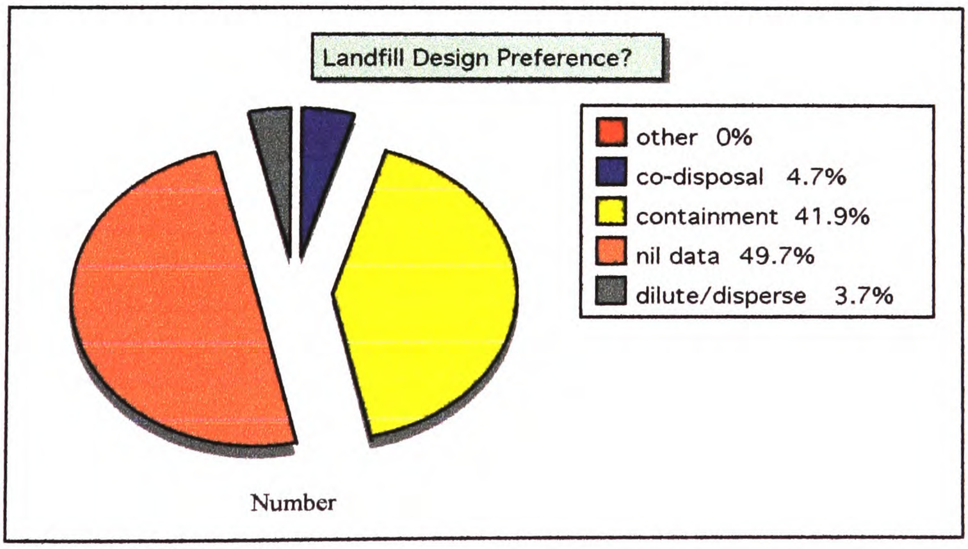

Figure 6.20: Landfill Design Preference

As expected the strong response here was for containment landfilling for future sites. This is a responsible approach and sits well with integrated waste management systems even though the pretreated waste residues are likely to be more benign and predictable in nature than untreated waste deposition. The choice of containment with pretreatment is the safe option for the Environment.

Question 21: Disposal Company?: Under this heading roughly equal returns were received for LAWDC companies' 88(19.1%) returns and NAWDC companies' 78(17%) returns. Joint venture options registered in 14(3%) returns with 43(9.3%) authorities advising that future waste disposal company arrangements were not confirmed at the time of the survey. A "Nil data" response of some 237(51.5%) returns was recorded. The data are presented in Figure 6.21

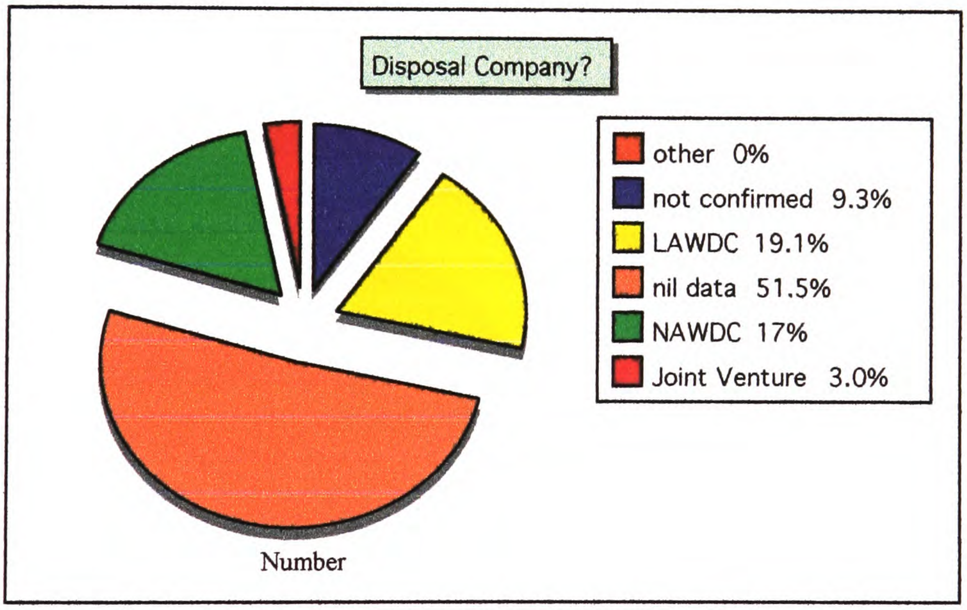

Figure 6.21: Disposal Company

With the changes in waste legislation local authority waste disposal operations are required to move forward as private companies divorced from the LA parent. The questionnaire results indicate almost equal distribution of former LA "companies" sitting alongside the intrinsically private waste operators. A small number of local authorities have chosen to embrace a 'joint venture' approach with private waste

contractors. As things move forward it will be interesting to observe if the truly private companies begin to exert their influence in the market via takeover of the LA linked firms.

Question 22: Disposal Within Authority?: Of the data responses the major selection was the disposal of waste within the boundary of the waste generating authority - some 108(24%) returns. The data show that only 13(2.9%) returns registered disposal outside the authority. Six (1.3%) returns detailed the typical one way mileage involved in the disposal of the authority's waste. A high "Nil data" response of 323(71.8%) returns was recorded. The data are presented in figure 6.22. High NIL response can be linked to operator and regulator desire to obscure a situation which confirms that waste disposal is not complying with the "proximity principle" but in fact large volumes of waste are being transported large distances outside the boundaries of the authorities where the waste is generated.

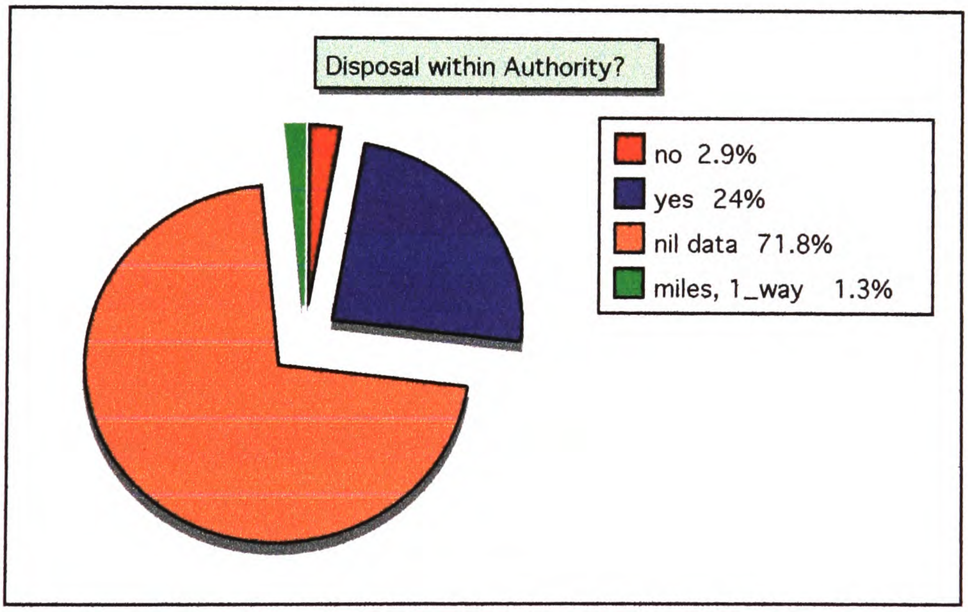

Figure 6.22: Disposals Within Authority

From the survey responses it is apparent that LA's anticipate disposal of refuse being maintained within the local authority boundary. This is now more likely with the rationalising of council boundaries and the establishment of larger unitary authorities. Nevertheless where convenient sites are identified they may serve a number of closely situated authorities involving some transboundary movements of

waste. This is already being investigated with respect to waste disposal in the border areas of Northern Ireland and the Republic of Ireland

6.4. Further Analysis

The questionnaire responses have been further analysed across data fields and this has yielded interesting patterns. These patterns are outlined below.

◇ A higher number of **** plus H landfills reported pollutant migration when compared to ***inc.H landfills. However, the proportion of **** plus H landfills reporting pollutant migration was slightly lower than the proportion recorded for *** plus H landfills. It is likely that the higher category sites employ more robust containment and management systems in recognition of the more hazardous wastes they contain. At the time of survey these systems appeared to have been doing their job but the high number of Nil Data returns against the question on pollutant migration shows the sensitivity for this area of enquiry. Further investigation in this area over time may prove revealing.

◇ A higher proportion of "dilute and disperse" sites acknowledged detectable pollutant migration than that recorded for containment sites. Again this confirms that containment sites seem to be performing better than the dilution and attenuation mechanisms embodied within the "dilute and disperse" philosophy. With waste pre-treatment the environmental performance of containment landfills should continue to improve if the high standard of care and attention to the containment and management systems is maintained for new sites. There should be no diminution of the principles of risk assessment or construction quality assurance even with waste pretreatment.

◇ Landfills returning a geomembrane alone as the basal sealing system had a higher proportion of records confirming pollutant migration when compared to clay lined landfills. Composite lined sites (geomembrane/clay) showed the best performance.

◇ Nearly 75% of sites citing mineral void as the design concept utilised clay in the

construction of the base lining system. It is likely that the clay materials were readily available at the site and that the void was the relic of previous clay extraction. Nearly 80% of mineral void concept landfills recorded the use of clay in their capping systems again supporting the previous statement on the link between extractive clay industries and the use of clays in containment systems.

◇ The percentage of Nil Data returns for controversial questions such as system failures and pollutant migration rise dramatically when compared to general questions such as design concept, base seals, capping etc.. This increase in Nil Data returns is also true for commercially sensitive information such as void space.

◇ 20% of containment landfills are recorded as producing power from landfill gas. Landfill gas utilisation needs to be dramatically increased to provide sustainable development and to assist in the battle against global warming. The proportion of gas to power use for containment sites is twice that for dilute and disperse sites - as anticipated. Nevertheless, some historic dilute and disperse sites do successfully utilise landfill gas. In the future, and allied to waste pretreatment, gas take -off will occur before waste disposal, and under more manageable, almost process engineering conditions, where environmental protection measures can be administered under more controlled conditions.

◇ Special waste/co-disposal site numbers show a close match. Alternative arrangements will need to be made for dealing with co-disposal wastes with the advent of the new landfill directive.

6.5. Chapter 6 Overview

Chapter 6 has revealed the following:

- Seventy council authorities were canvassed for information on landfill sites in England and Wales.
- Nearly 70% of questionnaire forms elicited some responses.
- Higher percentage returns were received for non controversial/non

commercial data such as construction concepts etc..

- Lower responses were received for commercially sensitive data such as void space, remaining life, system failures, pollution incidents etc..
- A lower percentage of **** plus H sites returned pollution incidents compared to *** plus H sites.
- A higher percentage of single geomembrane lined sites reported pollution migration compared to clay lined sites.
- The percentage of clay sites with pollution migration was slightly greater than the percentage of composite liner sites reporting pollution migration - both a lesser percentage than geomembrane lined only sites. Composite lining was confirmed as performing better in service in line with the preferred minimum basal lining requirement espoused by the UK Environment Agency.
- A significant proportion of the Nil Data returns is explained by sites for which licences were surrendered with the advent of the Waste Management Licence Regulations in May 1994.
- Containment sites are recorded as performing better than "dilute and disperse" sites with respect to detectable pollutant migration.
- The percentage of sites utilising landfill gas is small and needs to be improved upon. A higher proportion of containment sites utilise landfill gas when compared to "dilute and disperse" sites.
- Encouraging responses were returned with respect to future waste management policy. A high proportion of responses showed that waste minimisation, recycling and pre-treatment were about to be embraced at the time of survey - combined with containment concepts for new landfills which will take pre-treated waste residues. This falls in line with the latest EU directives and reacts against the focus on bio-reactor landfills espoused at the time by UK DoE.

7. CHAPTER 7 - LEGISLATIVE TRENDS

7.1. European View Through The 1990's

Landfill - European Update: In May 1996 the European Parliament voted overwhelmingly to reject the Council Directive on the Landfilling of Waste - first proposed by the Commission of the European Communities in 1990. Rejection was sparked by a proposed amendment from Portugal and Eire calling for exemption of smaller landfills serving rural areas with populations of less than 35 inhabitants per square kilometre.

During debate it was demonstrated that such an exemption would affect more than 50% of the EC's land area - as such excluding such areas from the Directive's full controls. The legal basis of the EC Treaty required that Parliament either accept or reject the directive. MEP's voted for rejection after being told that there was no indication from the Council that it would be prepared to remove the exemption.

Following the vote the Council, aware that several Member States shared the view of the European Parliament, noted that it could not act and accordingly invited the Commission to present a new proposal as soon as possible. A new proposal for a Council Directive on the landfilling of waste was presented by the Commission on 5 March, 1997 (Ref 97/0085(SYN)) - and ratified by the European Parliament in June 1999. This new Landfill Directive (LFD) is due to be enacted in the UK shortly.

Scope of the New Landfill Directive: The new LFD draws on the changes in development in the waste sector and on the changes in legislative landscape since the discussion on the original proposal commenced in July 1991. The new LFD is an updated version of the original which takes account of the main elements of the 1995 Common Position of the Council and the concerns expressed by the European Parliament.

Europe's Experience Of The Environmental Impact of Landfilling: The 1996 Commission Communication on the review of the Community Strategy for Waste

Management confirmed the hierarchy of waste principles established by the Communication of 1989. Waste prevention remains the first priority, followed by recovery and finally by the safe disposal of waste i.e. landfilling. In the Community Waste Strategy landfilling represents the least desirable option, **the choice of last resort !** This arises from the substantial negative impacts that landfill operations can have on the environment. These can include emissions of hazardous substances to soil and groundwater, emissions of methane into the atmosphere, dust, noise, explosion risks and deterioration of land. Landfilling on its own brings no benefits in the encouragement of waste prevention and does not beneficially use waste as a resource, the latter strategies having a higher place in the Community Waste Strategy.

Severe problems linked to landfilling have been reflected in the numerous complaints received by the European Parliament from Member States. During 1995/6 alone 38 petitions concerning landfills were submitted to the Commission. The petitions, arose mainly from Spain, Portugal, Italy, and Ireland. In addition to petitions the Commission had received at least 60 complaints concerning landfilling since 1989. These related to landfills in Italy, France, Germany, Belgium, Spain, Portugal, Greece, Ireland and the United Kingdom. An extreme example relates to a spill of 100,000 tonnes of municipal waste in La Coruna, Spain, leading to the death of one person. The destroyed landfill poses a threat to the marine environment and to the 250,000 inhabitants of the city.

The list of complaints also reflected the non implementation of existing Community legislation. The obligations of Member States had already been set out in Directive 75/442/EEC, Article 4. However, Member States like Greece, Ireland, and Portugal had not managed to prevent uncontrolled landfilling thereby contravening Directive 75/442/EEC.

Objectives of the Landfill Directive: In line with Article 130 r(2) of the Treaty, environmental policy is to be founded on a high level of protection. The new LFD aims to ensure the adoption of high standards for the disposal of waste in the European Union whilst stimulating waste prevention via recycling and the recovery of waste. A key to this is the creation of a level playing field with regard to the cost

of disposal whilst at the same time avoiding the unnecessary transportation of waste. Today in Member States the price charged for the landfilling of wastes does not appear to reflect the actual cost for the environment and for society in general. In the new proposal Member States are required to ensure that the externalities of landfilling are included when estimating the total costs associated with this disposal route. As a result landfill tax levels in the UK can be expected to rise significantly in the future.

Control of Methane Emissions: Since the political agreement on the Common Position was reached in 1995 focus has now also turned to the problems associated with methane production - particularly methane generated from landfills. Methane is a contributor to global warming, second only to the impact generated by carbon dioxide. The main sources of methane emission are the sectors of agriculture, waste and energy. Waste contributes 32% to the total amount of methane produced and most of that 32% comes from landfills.

A strategy document for reducing methane emissions has been adopted by the Commission. The strategy concludes that the most effective option for cutting back on methane production is a reduction in the landfilling of waste. The new proposal for a Directive on Landfilling is fully in line with this philosophy. Main planks of the new proposal for a directive include composting and biogas treatment as alternatives to the landfilling of biodegradable wastes. Composting waste represents an aerobic treatment of biodegradable waste which generates compost and carbon dioxide, and biogas plants represent the most efficient way to generate and utilise methane gas. Closed carbon loops can be adopted with these technologies

Pre-treatment of Wastes: In line with practices and developments in several Member States a provision is introduced which requires that waste be treated (or transformed) before it is landfilled. Treatment serves to reduce the volume or hazardous nature of the waste and thus this facilitates ease of handling and enhances the process of waste recovery. Pre-treatment is defined as 'physical, chemical or biological processes, including sorting, that change the characteristics of the waste in order to reduce its volume or hazardous nature and facilitate its handling or recovery'. This broad

definition has been adopted to encourage methods other than incineration prior to landfilling of waste.

Ban on Disposal of Tyres: The disposal of used tyres (whole or shredded) will be prohibited. The Priority Waste Stream Working Group on used tyres, which was set up by the Commission in 1991, proposed a ban on the landfilling of tyres in its final conclusions in September, 1993. This has been taken into account in the new proposal in order to prevent landfilled tyres and shredded tyres from making landfill sites unstable and to reduce the risk of fire. The ban on the landfilling of both whole tyres and shredded tyres will encourage the recovery of tyres and thus save resources.

Increased Cost of Landfilling: The price charged for the disposal of any type of waste should cover at a minimum all costs involved in the setting up and operation of a landfill site. The price, however, should also include the cost of environmental externalities, the provision of financial security as well as the estimated costs of the closure and aftercare of the site for a period of at least 50 years. This provision aims at restoring the balance between the costs of landfilling, which are presented as being too low, and the costs of other treatment methods such as environmentally sound recovery operations, for which the costs are relatively high. This is in line with the Common Position of the Member States.

No Joint Disposal of Hazardous and Non-Hazardous Wastes: Joint disposal of hazardous and non-hazardous waste will be prohibited by the new Proposal. In the majority of Member States joint disposal of hazardous and non-hazardous waste is no longer practised. Also, already in the Common Position of the Council of 1995 it was stated that joint disposal should be phased out within the next 5 years or so. The benefits for the Environment will be a decrease in the contamination of soil and groundwater and an improvement in the control of landfills.

General Requirements for Landfills: The general environmental requirements for all classes of landfills (Annex 1 of the new Proposal) have been improved by introducing a minimum distance from landfills to residential areas, by emphasising

the surface sealing of the sites, by prohibiting the spreading of dirt onto public roads and the surroundings and finally by requiring fencing and control of access to the sites for security reasons in order to avoid illegal dumping.-

The bulk of the above recommendations are now included within the current Landfill Directive of the European Union. It is expected that these provisions will now be enacted within United Kingdom law in the near future - 2001.

7.2. United Kingdom View Through The 1990's

Bioreactor Landfill: Debate on the "flushing bioreactor" landfill within the UK reached a crucial stage during the 1990's with proposals for a multi-million pound demonstration project funded by the waste industry and with landfill tax rebates. However, such a large scale demonstration has never materialised due to diverging opinion within the industry's trade body over the practical merits of the bioreactor landfill principle - given the debate raging within the European Union on the new Landfill Directive based on waste pre-treatment..

Since 1994/95 the UK Government had moved policy behind the yet to be proven bioreactor technology in which wastes would be saturated with water and flushed repeatedly to speed their degradation and remove contaminants. The advantage this offered was that unlike previous landfill practices which required pollution control and monitoring at many sites for hundreds of years , a bioreactor could be compatible with sustainable development by achieving stabilisation within a generation or so. (ENDS 265 1997 pp 11 - 41) (Annex, R.P. (1996)). Partly, the support for the bioreactor was driven by UK opposition to EC landfill policy in much the same way as the UK fought to maintain the co-disposal of hazardous liquid wastes within Municipal Solid Waste Landfills. That fight has now been lost.

A key issue in developing a flushing bioreactor related to whether it would be cost competitive with alternative solutions such as incineration and anaerobic digestion. The Institute of Wastes Management (IWM) working group on sustainable landfill

indicates that a bioreactor landfill located in clay geology may impose additional net costs of just £9.90. per tonne compared to a conventional site. However this rises to £23.22. for landfills in non-clay mineral extractions - presumably due to the greater cost of installing lining and groundwater protection systems.

The cost comparisons were presented to IWM's annual conference (June 1997) and took into account benefits such as reduced aftercare costs, lower risks of uncontrolled releases, and better uses of landfill void space - which had not been considered in earlier assessments. Obviously one of the major additional costs for a bioreactor landfill would be those associated with the leachate recirculation system.

The extra costs, though considerable compared with current landfill prices - usually less than £20 per tonne including landfill taxes - indicate that a bioreactor may in some cases be competitive alongside competing technologies such as incineration. Even so, unless backed by regulation it was unlikely, given the market conditions that the "quantum leap" to the bioreactor would be made.

Another view relates to the water supply requirement needed to support bioreactor landfill facilities. Estimates made by Dr Richard Beavan at Southampton University estimate that 500 million cubic metres of water per year would be needed for the 100 million tonnes of UK waste that would require flushing. This is equivalent to 4.25% of the water supply in England and Wales, although it is admitted that untreated and sewage effluent water could be used. The recirculation of leachate would also help to accelerate the stabilisation of municipal landfills. (Harper, S.R., Poland, F.G. (1998))

IWM and Environmental Services Association (ESA) had planned to join forces to set up a demonstration project in the late 1990's. **Entrust** funding (derived from landfill tax revenues) status was to be incorporated within the research body, allowing waste management firms to recoup up to 90% of their contributions from the public purse through the landfill tax credits scheme. Proposals for the bodies research programme were drafted but the demonstration project is yet to come about.

It had also become increasingly recognised that due to the conflicting opinions

consensus on research priorities would be hard to achieve. A number of waste management firms are committed to other technologies and are opposed to the bioreactor landfill concept. Whilst research data to help waste degradation in landfills in general terms is a worthy goal, the panacea offered via the development of full scale flushing bioreactor landfills has been described by some as "cloud cuckoo land". They argue that the last place to "process" waste (to achieve stabilisation) is in a landfill site - it obviously requires a dedicated process plant where conditions can be accurately monitored and controlled. There is a view that the enthusiastic support thrown behind the bioreactor landfill had run dangerously out of control - perpetuated in part by the "guru experts" at the then Department of Environment.

Alternatives have been floated within IWM. These include composting as a post-landfill treatment, where wastes would be dug up after some years of accelerated anaerobic degradation in the landfill cell, and composted in windrows before final deposition. Another view is that a two stage anaerobic process has many benefits on the small scale with wastes being treated in an easily managed "accelerator" cell to bring about early stabilisation prior to deposition of the wastes in their final resting place. The two stage process has the advantage that it would still utilise deep quarries for the final landfill phase. A disadvantage from a planning perspective is that there would be a delay to final restoration.

A final view is that the "sustainable landfill" concept would have to incorporate an anaerobic digester. This would take the form of a dedicated element of process plant used as pretreatment ahead of the landfill phase. With a reduced final waste mass there would also be reductions in the landfill tax payable. Pre-treatment ahead of landfill also just happens to match neatly with the latest EC directive!

Recent research on a Government funded waste project has returned mixed results according to a recently published report (CWM 050/96, Landfill 2000: A Field Trial of Accelerated Waste Stabilisation from the Waste Management Information Bureau : Tel. 01235 463162). The project, which involved deposition of 1,000 tonnes of household waste mixed with sewage sludge in a cell 5 metres deep, indicated that the landfill successfully broke down putrescible wastes but that more recalcitrant

materials such as paper (a significant part of MSW) was not successfully reduced or stabilised. The study noted that after 4 years burial and with the recirculation of leachates about 58% of the readily available landfill gas had been generated. The researchers predict that the test cell will take only seven years to stabilise but this relates only to the putrescible fraction of the waste. Paper and textiles would not degrade in this period, possibly because of the role of lignin as a barrier to microbial attack. Waste characteristics changed "little" during the four year study.

Sorting and separation of waste and textile/paper products in advance of flushing of putrescible wastes is one way of overcoming the limitations of accelerated stabilisation.

7.3. Debate: The Future for Landfill and Containment

There seems to be no doubt that the continuing sole dependence on the landfilling of waste is now going to reduce. This reduction in landfilling will be brought about by tighter design and operational control over landfill developments and also by fiscal control. The latter includes items such as the fees and charges levied on the development and running of landfill and also the introduction of landfill tax on materials directed to landfill. In this way the cost attractiveness of landfill when compared to alternative waste prevention, minimisation and transformation techniques can be reversed. Tax incentives linked to the adoption of alternative technologies will accelerate this reversal.

In this way the volume of materials directed to landfill will fall, thereby protecting valuable void space assets. The alternative technologies will minimise final residues and also assist in combating the production of high percentages of biodegradable wastes destined for landfill. Greater control will therefore be exerted over the minimisation of greenhouse gases such as carbon dioxide and methane. This is the preferred European Union approach. (Daily Telegraph (Weekend) 29 March 1997)

This approach is embodied in the new European Landfill Directive. Support is given to the concepts of waste prevention, recycling and eco-friendly waste transformation

processes. A prohibition is included in respect of the directing of biodegradable waste to landfills, linked also to a prohibition of the practice of co-disposal of hazardous and non-hazardous waste. The Directive includes a ban on the landfilling of used tyres, whole or shredded.

The requirement for financial provision to cover closure costs and a period of 50 years of aftercare is included. Emphasis is placed on the pre-treatment of waste to reduce disposal volumes and to lessen the hazardous properties of the disposed residues.

What is this likely to mean for landfill ? In the short term there is likely to be little instant effect - but inevitably, it seems there will be a gradual shift away from landfill towards newer technologies. (Daily Telegraph (Weekend), 29 March 1997) & (Daily Telegraph March 1997) Provided that these alternatives perform and do provide enhanced environmental benefits then their adoption is to be supported and seems assured. The long term impact on landfilling will be a shift away from 'Active Process' dumps where the often unpredictable chemical, biological and physical transformation of wastes within the landfill biomass is accepted, towards more benign facilities where burial of the minimised residue volume is the major focus and the over reliance on the proper function of linings and cappings, leachate and gas control is less critical. Burial of substances of lesser hazard and reduced biodegradability will result in lower production of leachate and methane gas at the landfill. Indeed, with careful control these concerns may possibly be eliminated. However, the leachable elements of any residue will have to be controlled and proper containment and by-product control and monitoring may not be totally avoided. Indeed, the new Landfill Directive includes strict controls in respect of these elements - Annex 1 of the Directive. These will be applicable especially in remote community areas where the concept of landfilling is likely to continue as the critical population mass of urban centres is absent making it difficult to invest in pre-treatment technologies.

With the prohibition of the biodegradable component of the waste stream the 'new dawn' of active bio-reactor landfills is unlikely to arrive. The debated research regarding leachate recirculation and flushing may not now take place on the grand

scale called for. More likely is a shift in focus to other non-landfill techniques for waste transformation and disposal. It seems that there is a momentum in favour of introducing these techniques into the waste industry on a much larger scale than is currently the case. With increased take-up of these processes comparative costs will eventually fall or at least be accepted as part of life. Landfill will be demoted into the bottom rank of the waste management hierarchy and then only for the more benign and pre-treated residues. Containment and management of 'dry' entombments will be the major focus. The optimism surrounding 'bio-reactor' landfill developments is considered too great a risk, given that the required technology is not proven at full scale and in close proximity to valuable and irreplaceable environmental resources.

The take up of the new technologies is likely to happen first in the major centres of population where space for landfill is restricted and where the transfer of large volumes of material is uneconomic. New York authorities have indicated that no new landfilling venture is ever likely to be commenced in the city. In future the emphasis will be centred on waste minimisation, home composting and centralised composting initiatives as a way of combating the 26,000 tonnes per day of MSW produced by the city's inhabitants of 7.5Million. Over a year this equates to 9.5M tonnes contributing to the city's Staten Island landfill which covers some 2,900 Acres (1160Ha). When finished the tip will comprise 4 pyramids each 435 feet (135m) high - one of the largest man made structures on the planet. (Outerbridge, T. (1994))

In major population centres within the UK evidence already abounds of the move towards pre-treatment processes as the front end to reduced residue placement in landfills. For example a "dirty" MRF system is planned for Ipswich - this will deal with 100,000 tonnes per annum of unsorted household waste enabling the local authority to achieve the immediate government recycling target of 25%. (Materials Recycling Weekly, 5 September (1997)) Dundee City Council is embarked upon the development of a Waste to Energy plant to deal with 120,000 tonnes per annum of domestic waste - The plant will generate via waste derived fuel and steam generators an output of 8 Mw. (Local Authority Waste & Environment, August 1997)

At Pitsea Landfill 25,000 tonnes of green waste will be diverted from landfill into a new composting complex. This comprises open-air windrows, eventually evolving into an enclosed tunnel set-up. Compost residues will be ecolabelled and marketed as a soil improver - which can also be used as a landfill restoration medium.

Elsewhere debate rages on the merits of incineration as a pre-treatment process. The London Planning Advisory Committee (LAPC) has previously recommended a moratorium on waste incineration in London until 2002 - at which time a review will take place.

As background it has been reported that incineration in the UK deals with 5% of MSW. In contrast the figures for continental Europe include Denmark (65%), France (42%), Netherlands (40%) and Germany (30%). (Local Authority Waste & Environment, (August 1997)) This approach now finds favour in the UK government's latest waste strategy document. (Ref: A Way With Waste (1999)) Within continental Europe the possibility of developing other alternatives to waste pre-treatment by incineration have been shunned. The options of treatment by pyrolysis or gasification are not favoured - in part because of the lack of data on operating costs, and lack of demonstrated previous reliable operation of these processes. (The Waste Manager, (December 1997))

By contrast the use of UK landfill tax funds to review options for waste composting is seen as a useful research field. Three trial projects have been identified by the Composting Association to assess the environmental impacts of composting, to prepare a guide for central composting and to technically review in vessel composting. (Local Authority Waste & Environment, (August 1997))

An interesting study has also been undertaken by USEPA - it found that waste to energy incineration in fact causes slightly higher greenhouse gas emissions than conventional landfilling. Waste minimisation at source combined with recycling were found to be the favoured option when considering the impact on global warming. The study indicates that certain wastes are in fact better landfilled - these include plastics where landfilling traps the carbon in the waste rather than incineration where

the production of more CO_2 occurs when compared to the burning of fossil fuels in conventional power stations. (ENDS No.270, (July 1997))

However, should history prove the new technologies to be ineffective or unable to cater for the waste stream quality and quantity then, landfill may yet find ultimate favour as the mass volume technology. Obviously, should this situation come about then there will be added benefit if research has been undertaken into the technology necessary to support 'bio-reactor' landfilling. There is a strong case for a number of 'model' landfills to be established at full scale, but in less environmentally sensitive locations, to establish whether the bio-reactor principle is viable in stabilising the landfill process within the target 30 year period. This is unlikely to happen if industry is expected to fund the research. Industry's eye is focused on investment in waste pre-treatment technologies. Large scale research into the bio-reactor will only happen with substantial UK government funding - the concept does not feature strongly in (A Way With Waste" (1999)).

7.4. Chapter 7 Overview

Chapter 7 has revealed the following:

- A new European Landfill Directive has emerged.
- The new Directive espouses waste pre-treatment.
- The new Directive will be enacted within UK law during the Year 2001.
- UK strategists had promoted advocacy of co-disposal and bio-reactor landfill technologies through the 1990's.
- No "full scale" trial of a bioreactor landfill has taken place in the UK.
- Take up of waste pre-treatment will make the bio-reactor landfill obsolete.
- Industry is now investing in the pre-treatment technologies attempting to catch up with the refinement of European systems.
- European countries have a longer history of waste incinerator development - a higher percentage of the waste stream is incinerated in continental Europe.
- The UK can now benefit from the evolution and improvement of incinerator technology that has taken place in Europe although the level of CO_2

emissions is an issue.

- The "full scale" bioreactor landfill trial is unlikely to happen now.

8. CHAPTER 8 - STUDY CONCLUSIONS

8.1. Main Findings

Main findings of this research are as set out below:

1. The urbanisation of human society has increased disposable waste volumes - the modern urban environment generating more throw-away packaging wastes compared to smaller volumes of putrescible green wastes as had been the case in the rural context.

2. In a modern technological society the disposal of domestic waste per inhabitant can be as high as 7 times body weight per annum.

3. A significant percentage (10%) of UK landfills canvassed and listed in the 1993 Site Digest did not appear in the 1996 version. Effectively these sites have ceased to operate - most probably because their design and operational concepts were out of step with the more rigorous groundwater protection based systems required under the Waste Management Licensing Regulations 1994. It is probable that the majority of these "disappeared" sites operated on the "dilute and disperse" principle.

4. Dilute and disperse sites had evolved out of a need to infill old mineral extraction pits - fitting with the planning policies of the time. Natural containment existed in many cases - but this comprised non homogeneous deposits with no reworking to achieve consistent low permeability containment. These "surrendered" sites may pose a threat to groundwater quality in future years.

5. Some dilute and disperse sites have continued to operate but these register at less than half of the containment sites. Even then the dilute and disperse responses received have by and large been linked to older parts of sites now continuing as containment sites - some 14% of the sites reporting containment.

6. From acceptance of dilute and disperse landfills in the 1970's this concept is now rarely used. Containment is now the accepted standard.

7. However, rather than evolution of containment landfills into more sophisticated, but potentially unpredictable bioreactor landfills, emphasis has now shifted to the need for "up-front" managed pre-treatment of wastes - with a more benign residue requiring landfilling. Containment will continue to be used but the concept of the large scale "bioreactor" landfill is now losing favour.

8. In the UK containment landfill design, whilst employing certain developed generic systems, leaves the actual design choice and system component selection to risk based appraisal techniques rather than prescriptive minimum standard guidance. There is close dialogue between designers and the regulators at the Environment Agency ensuring that appropriate containment designs are matched to site conditions, status of groundwater resource and anticipated waste stream. Over-design is avoided through this approach and system performance is always overviewed through long term monitoring for gas and groundwater parameters.

9. Clay base liners and caps are the most widely used reflecting general UK geology. Synthetic liners, however, are now used in significant and rising numbers. Increasing numbers of composite clay/synthetic systems are being used and through the risk appraisal approach this solution is often selected as the appropriate option. Geosynthetic Clay Liners (GCLs) are now starting to be used more widely.

10. Both single clay and single geomembrane designs had a similar proportion of sites reporting pollution migration. Composite lined sites had a lower proportion of locations reporting pollution migration.

11. There is very little take up of low grade or secondary materials for use in base lining or cap systems. This must be seen as disappointing and this is an area that needs to be worked on with regulators to raise the profile and valuable role of secondary materials within landfill containment designs. Otherwise the secondary materials will just contribute to the overall waste stream rather than playing a useful role in landfill systems and operations.

12. There is increasing take up of waste to energy schemes - but still a very minority

percentage. Containment landfills are, by and large, the vehicle to date in the UK for gas to energy schemes - twice the proportion of " dilute and disperse" sites. Much scope exists for expanding energy from waste schemes. Energy from Waste (EfW) is a favoured technology in "Waste Strategy 2000". However, the number of incinerator facilities this will require is significant and the feasibility of installing incinerators in the required number and time scale is already being questioned (The Independent 24 January 2000). It is claimed that the opportunities for achieving recycling target percentages may well have been missed. The UK's historic reliance on landfill may be at the root of this impasse and this has not been helped by the UK DoE's insistence through the 1990s that the bioreactor landfill was a viable and commercially feasible proposition. Whilst this was being argued in the UK our European partners were refining their waste pre-treatment technologies. Life Cycle Analysis (LCA) will be increasingly used to optimise the mix of future systems.

13. At the time of survey there was already strong support for building ancillary pre-treatment methods to complement landfilling - driven by Agenda 21 recycling initiatives arising from the Rio Summit 1992. Total returns reported for the range of pre-treatment methods roughly match the returns confirming the continuing use of landfill as part of an overall waste management strategy. This demonstrates that landfills will still be required for the disposal of the pre-treated waste residues, albeit at a reduced filling rate. This will preserve landfill space for a longer period and ease the pressure on void space in areas such as the south east of England.

14. Continental Europe uses more pre-treatment than the UK. Incineration technology has become increasingly perfected there - in the UK bad experiences of the 1970's and reliance on landfill has meant that incineration has not evolved at the same pace. The UK should, however, now benefit from the advances made in continental Europe - effectively importing tried and tested and highly efficient incineration technology. See **Appendix 8** for new EfW plans for Colnbrook, Berkshire, UK.

15. The large scale investments required in waste pre-treatment systems and in the supporting containment landfills will drive the development of larger regional facilities. Their size and economies of scale will aid sustainability.

8.2. Summary Thoughts and Observations

This research of landfill containment and waste management systems has been aided by the wealth of literature available on the subject. Sources range from text books, journal articles, newspaper articles, research documents, seminar notes and the Internet etc.. The breadth of information is wide and it is of importance to discipline oneself to drawing on salient information only for the area of research under consideration. There is much more information out there and further detailed studies on specific aspects of waste management can draw strongly on this. Interesting areas of study available under this heading will include the implementation of waste pre-treatment in the European Union, reclamation/restoration of older landfills, leachate treatment methods, landfill gas management and waste to energy schemes etc..

A disappointment in undertaking the research has been the failure of the DoE (now DETR) to release data on the study sites from their national GIS and database of waste management facilities. This would have provided a more comprehensive data-set with fewer gaps. Nonetheless, I am extremely grateful to those Local Authorities and Waste Companies who have provided data, which although incomplete in many cases, does give a good insight to the waste management industry through the last decade of the 20th Century.

We are now entering the 21st Century and there are many challenges ahead for the waste management industry in the United Kingdom and around the globe. The take-up of waste pretreatment will be interesting to monitor in the UK and this will run in parallel with landfilling of pretreated waste residues. From bin to burial the tracking of wastes is now going to be monitored as never before. The concept of Life Cycle Analysis (LCA) will be used as a selection tool in the choice of collection procedures, pretreatment processes and landfill management techniques. The UK Environment Agency has now developed (December 1999) a LCA software package for this purpose - WISARD.

With regard to landfill containment there are still areas of concern in the use of HDPE geomembranes (**Appendix 9**), compacted clay liners (CCLs) (**Appendix 10**) and geosynthetic clay liners (GCLs) (**Appendix 11**). Innovative research will need to be continually fostered to improve our understanding of the performance and durability of these materials within waste containment barriers.

It will also be interesting to see how integrated waste management sites or "parks" develop in the UK. This will need the planning authorities to play an active role in providing the appropriate planning framework within which the full range of waste management activities can develop. As a flavour of the future for the UK, an example of how this has been achieved at the VAR facility, near Apledoorn in the Netherlands is summarised in **Appendix 12**. This gives a clear and optimistic pointer to a sustainable solution for society's waste dilemma.

8.3. Containment Strategy Options:

In modern landfills the message on the diffusive transport mechanism has been recognised, hence the move towards multi layer liners incorporating not only clay but synthetics with back up leak detection and disposal systems. The complementary properties of geomembranes and GCL's has also proved attractive as these materials are considerably less profligate in terms of usable void displacement.

In the multi-layer system should the primary liner be breached the monitoring system will identify the breakthrough of contaminants and remedial actions such as pumping can then be instigated. The secondary liner will protect the environment while the remedial actions are instigated. The mechanism of diffusion and the potential risk is now clearly recognised and the scale of protection will be selected on the basis of the wastes contained, local geology and the exposure risk to groundwater resources.

Using this approach the respective weaknesses in both geosynthetic and clay/GCL mineral liners can be ameliorated with the best properties of both materials being utilised. Current thinking by experts in the US tends towards adopting double liner

systems as a minimum for MSW waste landfills. These systems will incorporate a leak detection layer beneath the primary liner system - draining towards a monitoring sump. Should leachates be detected in the leak detection sump, above certain leakage rate criteria, then previously agreed Remedial Action Plans can be mobilised to deal with the situation.

This approach is seen to be more workable and responsive to leakage development than perimeter monitoring boreholes which are relatively widely spaced. Defects in the lining system, should they occur, will tend to be small leading to elongated (thin) plumes of pollution. There is a high probability that such leakage will not be detected by perimeter monitoring boreholes. On the other hand, with a leak detection layer, and a secondary liner the installation will act as a large lysimeter, accurately demonstrating precise quantities of leakage.

8.4. Further Recommended Study Areas

The following further research areas are suggested by way of illustration. Many more research avenues in this subject area exist and will continue to develop.

- **Pursue Environment Agency GIS data for landfills and other licensed waste facilities. Analyse data in new ways but in future use the Microsoft Access database software - this has been the platform for the EA exercise. This form of "blue sky" research should be encouraged by the EA - a further negative response would be disappointing. An enquiry through EA regional centres is recommended as the active operation has now passed from the DoE originators.**

- **Using the EA data, if released, a study of the take up of waste pre-treatment technologies would be interesting. The impact of the new European Landfill Directive should be observed as the current decade unfolds and the attainment of non-landfill based targets should also be monitored.**

- **Also from the updates of the EA GIS data, the number of sites reaching "completion" or licence surrender should be monitored as we move through the**

decade. Comparison should be made of "dilute and disperse" performance against containment. In addition, comparison of putrescible containment landfill completions against the speed of completion for the new breed of "pre-treated" residue landfills would provide useful data.

- A more thorough investigation of the geographic distribution of landfills should be carried out. It is suspected that the greatest concentrations of landfills are in areas of previous extractive industries e.g. the pottery areas of Stafford. This can be viewed pictorially with the recent availability of the Domesday 2000 aerial photography coverage of the entire British Isles. Alternatively, it would be useful to obtain release of the EA GIS landfill boundary mapping data and compare this with aerial photography to assess general restoration standards.

- Consultation with geomembrane and geotextile manufacturers and installers for their project listings would provide more background data on the design approaches used for containment landfill sites.

- Gather data on the different types of geomembrane and geotextiles used. This can be linked back to data from site monitoring on environmental performance. Will the stress crack concerns relating to HDPE liners materialise before wastes degrade ? Will the use of more conformable and less stress susceptible materials such as polypropylene emerge ? Will heavier weight geotextiles be employed by the landfill operators to ensure better long term protection of the critical geomembrane liner component.

- From a review of updated EA data (if released), it would be possible to identify developing regional trends in the location of high investment waste management parks incorporating waste pretreatment, energy from waste and waste residue landfilling. These "super" sites are likely to be developed and used by neighbourhood groups of local authorities.

- It is anticipated that the sparsity of data so far accumulated regarding pollution incidents relating to landfills could be supplemented with data from the EA survey.

This avenue should be pursued.

- Again, through consultation with the manufacturers of specialist engineering products, enquire as to the take up and development of difficult steep sided and "piggyback" landfill sites. As engineering technologies improve and with the pressures exerted for more void space the realisation of more intricate designs can be expected. A review of litigation records linked to engineering failures at landfill sites would also be interesting. One could suspect that a number of failures would come to light as the more difficult or marginal sites are tackled. This has already happened with the "first wave" of containment design pioneers, but the optimistic message must be that these set-backs have been overcome and much benefit has been gained in the "science" of landfill design and the evolution of specialist containment products

- In all of this it will also be important and courteous to canvass relevant environmental pressure groups, such as GreenPeace and Friends of the Earth, to seek any interesting data they have on modern containment landfill designs and their performance. Feedback on these groups' favoured pretreatment technologies would also prove interesting and this could be compared to the approach of industry and individual governments. A study in the US of dioxin impacts on the Great Lakes has shown that, dioxin free, alternatives to processes such as MSW incineration do exist and should be promoted. (Commoner, B., Cohen, M., et al (1996))

- Follow up European Union initiatives on the management of hazardous wastes, standardisation of waste classifications and statistics, and proposals for the management of electronic component wastes etc..

- Extend liner and capping standards review to include other major countries including Canada, Australia, New Zealand, France, Russia, India, China etc..

APPENDICES

APPENDIX 1

Example of LandGem Landfill Gas Generation Model

AUTHORITY ********

********** LANDFILL**

PREDICTION OF LANDFILL GAS GENERATION

JULY 1999

Prepared for:
Authority ********

Prepared by:
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29 Cathedral Road
Cardiff
CF1 9HA

AUTHORITY ********

Report Title	:	******** Landfill Facility Prediction of Landfill Gas Generation
Report Status	:	Draft - Version 2
Date of Issue	:	June 1999
Job No.	:	BECCF*******
Prepared by	:	.... (K Davies/N Pedoe)
Checked by	:	.... (K Davies)
Check Cat.	:	B
Approved by	:	.... (A Dolecki)

CONTENTS

1 INTRODUCTION

1.1 Introduction

1.1.1 In support of Authority ********'s (CCC) waste licence submissions for the eastern landfill extension at ********, PB Kennedy & Donkin Limited (PBKD) has been appointed to undertake predictive modelling of gas generation volumes.

1.2 Details of the model runs to be undertaken are set out in PBKD's offer letter dated ***** - see Appendix 1 *(Not Included)*.

1.3 Descriptions of the modelling software used, the models tested, reported results and implications for gas management are included in subsequent sections of this report as follows:

Section 2 - Software Details.
Section 3 - Models Tested.
Section 4 - Results and Conclusions.
Section 5 - Implications for Gas Management.

2 SOFTWARE DETAILS

2.1 In undertaking the prediction modelling of landfill gas generation rates at ******** Landfill, PBKD has used the US Environmental Protection Agency's (USEPA) LandGEM (Landfill Gas Emissions) software, Version 2.

2.2 LandGEM can be used to estimate emission rates for methane and carbon dioxide.

2.3 The model is based on a first order decay equation, as follows:

Rate = k Lo e^{-kt}

- where **k** is the rate constant, **Lo** is the ultimate yield and **t** is the time base.

2.4 Options within the software programme include default selections for **k** and **Lo**. For this modelling exercise we have selected the US Clean Air Act (CAA) default option which uses the following values:

k = 0.05 1/year
Lo = 170 m^3/Mg of refuse.

2.5 The CAA default values in the model provide emission estimates that would reflect the expected maximum emissions - anticipated worst case scenario. A 1 : 1 volume ratio of carbon dioxide (CO_2) to methane (CH_4) has been used in the model.

3 MODELS TESTED

3.1 For the purpose of initial modelling total waste volume assessments have been used, including inerts. However, in assessing recoverable gas volumes appropriate adjustments are required to reflect the waste mix and this is discussed in Section 5. Three basic (unadjusted) LandGem waste input models have been set up by PBKD. These are as follows:

3.2 Model 1 - ******** South

This model looks at the waste deposits served by the current '****' gas to energy plant. The total volume of waste is assessed as 3.8 M m^3 including the 800,000 m^3 up-fill consent for ******** South. The waste input period runs from 1973 - 1999.

3.3 Model 2 - ******** East

This model simulates the waste tipping period envisaged for the newly constructed east extension containment area. Total waste volume modelled is some 2.9 M m^3 placed over the period 1999 - 2010. An average deposit rate of about 300,000 m^3 per annum has been used. Separate gas handling facilities for the East extension are to be considered - possibly sited on the seaward side of the landfill.

3.4 Model 3 - Total Waste Volume

As a comparison the total ******** waste volume of 6.7 M ^{3}m (3.8 M ^{3}m + 2.9 M ^{3}m) has been modelled over an input period of 1973 - 2010. Waste volume inputs have been increased in the model from a lower bound value of about 50,000 ^{3}m (Mg) per annum in the early years of tipping (as for Model 1) to the current and predicted 300,000 m^3 (Mg) per annum input now experienced.

3.5 An option in the LandGEM software relates to the selection of non co-disposal waste or co-disposal (MSW plus some hazardous) wastes. As a comparison Models 1 and 3 have been re-run as Models 1A and 3A to simulate the impact of landfilling co-disposal wastes on the generation of the primary landfill gases - carbon dioxide CO_2 and methane CH_4.

3.6 Model 2 - east extension has only been run under the non co-disposal option reflecting its operation under containment principles and the newer licence conditions applying to the extension area.

4 RESULTS AND CONCLUSIONS

4.1 Results

4.1.1 The model results for predicted peak CO_2 and CH_4 emissions for each of the models tested are summarised below

Model	CO_2 M^3/year	CH_4 M^3/year	Peak Year	Depletion Year
1. ******** South (non co-disposal)	21,990,000	21,990,000	2000	2199
1A. ******** South (co-disposal)	21,990,000	21,990,000	2000	2199
2. ******** East (non co-disposal)	19,480,000	19,480,000	2009	2209
3. ******** Total (non co-disposal)	33,000,000	33,000,000	2010	2209
3A. ******** Total (co-disposal)	33,000,000	33,000,000	2010	2209

4.1.2 Full text results and graphical plots of each of the model runs are included within Appendices B - F.

4.2 Conclusions

4.2.1 The models predicted no difference in the emission rates for either methane or carbon dioxide for the domestic waste or the co-disposal options. Other trace elements will be more susceptible to the effects of co-disposal filling.

4.2.2 The results of the predictions show that the peak emission rate for the primary landfill gases occurs in 2000 for ******** south, in 2009 for the eastern extension and in 2010 for the total volume model.

5 IMPLICATIONS FOR GAS MANAGEMENT

5.1 In running the ******** models the predicted gas generation figures assume the waste mass is fully comprised of Municipal Solid Waste. The waste input streams for ******** comprise to date, however, of some 45% Domestic (MSW), 15% commercial and about 40% inerts.

5.2 The total model predictions will thus in reality not be achieved. To take account of the inert waste element (which includes daily cover soils) and acknowledged inefficiencies in gas to energy capture rates a recoverable figure of 50% of gas prediction figures can be used when considering gas handling requirements.

5.3 The current gas to energy compound serving ******** South has three 'engines' each capable of handling some 650 m³ landfill gas per hour. The ancillary gas flare has a peak gas handling capacity of about 1,500 m³ per hour.

5.4 Using these figures the current ******** South engines and a partially utilised flare can deal with just over 20 million cubic metres of landfill gas per annum (about 2,000 m³ to 2,500 m³ gas/hr). This is only half of the total gas volume prediction (CO_2 and CH_4) from the model. This is to be expected in view of the significant inert waste element of 40% as explained in 5.2. Allowing for this there appears to be good accord between the adjusted gas prediction (50% of model) and the actual gas handling capabilities at the site.

5.5 Using this assessment one can provide some guidance for on-going gas management at ******** South and ******** East. Gas volume prediction tables and curves for CH_4 for ******** South and ******** East (non co-disposal) are presented at Appendix G - together with the composite (or Total) prediction curve. As the dataset depicts only methane (50% of total LFG value) this actually represents a prediction of total landfill gas for ******** - with due allowance for the near 50% inerts waste stream. The curves have been used as the basis for guidance for gas management at ********.

5.6 From the curves the following gas management guidance programme has been devised.

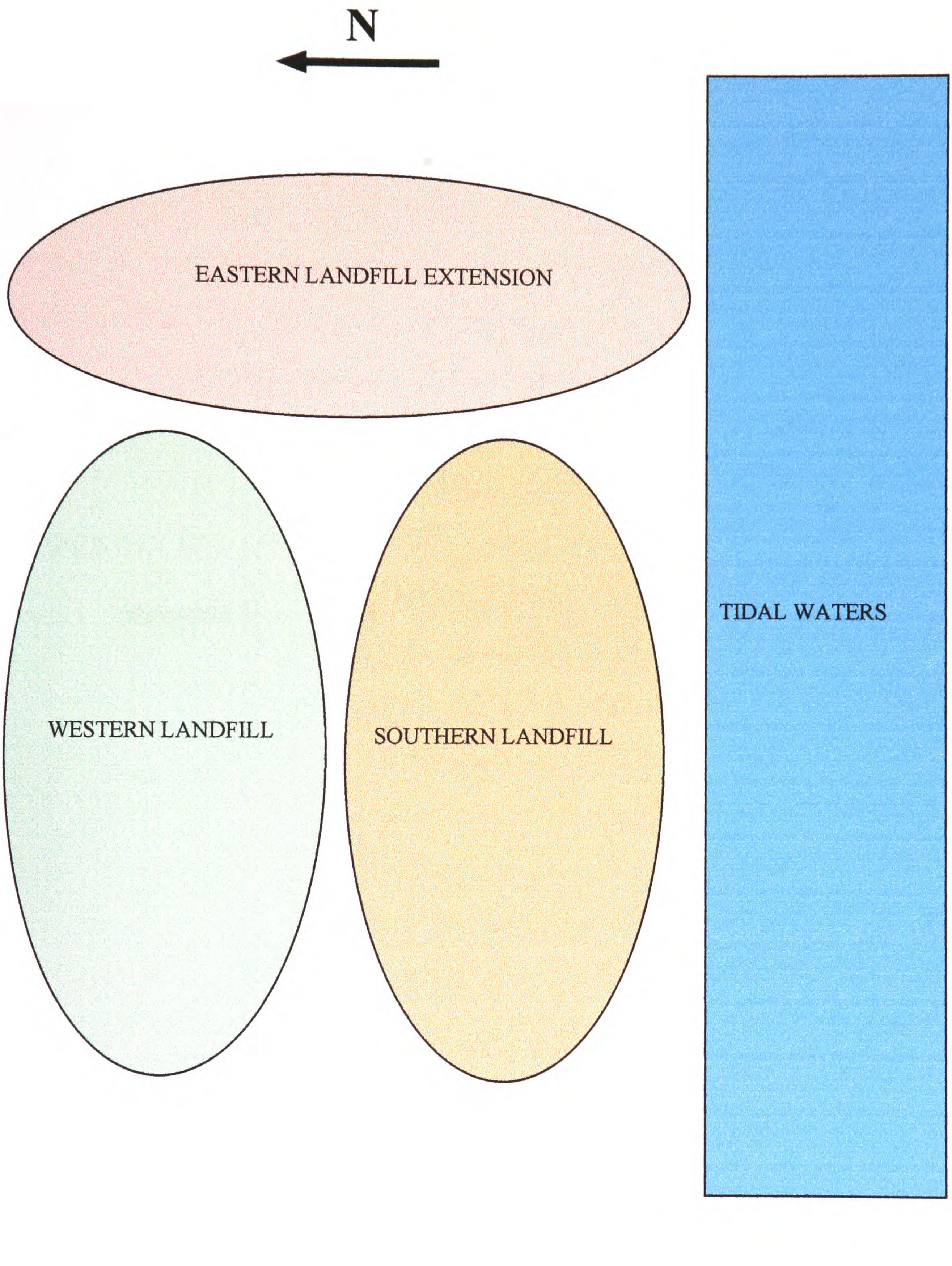
Year	******** South	******** East
2000 - 2003	3 Engines + Flare	Cell 1 to ******** South Flare
2003	3 Engines + Flare	Establish ******** East Flare
2004	3 Engines + Flare	2 Engines + Flare
2007	3 Engines + Flare	3 Engines + Flare
2007 - 2015S/2016E	2 Engines + Flare	3 Engines + Flare
2015S/2016E - 2025S/2024E	Flare	2 Engines + Flare
From 2025S / 2024E	Flare	Flare

The details are annotated on the gas curves at Appendix G.

5.7 The above is based on predictive modelling and assumptions on waste input rates using current tipping data. Presence of effective intermediate and final capping at ******** East is also anticipated. Waste input rates may, however, change and waste composition and gas producing potential may vary over time. It is important therefore that firm gas management programmes be based on actual site monitoring data and gas recovery pumping trials. Gas monitoring is anticipated to commence at ******** Eastern extension after the first six months of tipping.

5.8 The tabulated guidance above does, however, indicate that in about Year 2006/2007 maximum engine and flare arrangements at ******** South and ******** East will coincide ie 3 engines and flare at each site.

5.9 In modelling gas dispersion effects it is advised that this composite arrangement of engines should be considered as the anticipated 'worst case'. Should gas pumping trials indicate that a higher number of engines is required it is recommended that further gas dispersion modelling be undertaken at that time.



APPENDIX 1 FIGURE 1 - DIAGRAMMATIC REPRESENTATION OF LANDFILL ELEMENTS FOR LANDGEM GAS EMISSIONS SIMULATION

APPENDIX B

Model 1 - [redacted] South (Domestic - no adjustment for inerts)

Carbon dioxide generation predictions for domestic wastes using CAA parameters for south area of [redacted] Landfill : waste input period 1973 - 2000

Model Parameters

Lo : 170.00 m^3 / Mg
k : 0.0500 1/yr
NMOC : 4000.00 ppmv
Methane : 50.0000 % volume
Carbon Dioxide : 50.0000 % volume

Landfill Parameters

Landfill type : No Co-Disposal
Year Opened : 1973 Current Year : 2000 Closure Year: 2000
Capacity : 3800000 Mg
Average Acceptance Rate Required from
Current Year to Closure Year : 0.00 Mg/year

Model Results

Year	Refuse In Place (Mg)	Carbon Dioxide Emission Rate (Mg/yr)	(Cubic m/yr)
1974	5.000E+04	7.780E+02	4.250E+05
1975	1.000E+05	1.518E+03	8.293E+05
1976	1.500E+05	2.222E+03	1.214E+06
1977	2.000E+05	2.892E+03	1.580E+06
1978	2.500E+05	3.528E+03	1.928E+06
1979	3.250E+05	4.523E+03	2.471E+06
1980	4.000E+05	5.470E+03	2.988E+06
1981	4.750E+05	6.370E+03	3.480E+06
1982	5.500E+05	7.226E+03	3.948E+06
1983	6.250E+05	8.041E+03	4.393E+06
1984	7.250E+05	9.204E+03	5.028E+06
1985	8.250E+05	1.031E+04	5.633E+06
1986	9.500E+05	1.175E+04	6.421E+06
1987	1.075E+06	1.313E+04	7.170E+06
1988	1.200E+06	1.443E+04	7.883E+06
1989	1.325E+06	1.567E+04	8.561E+06
1990	1.450E+06	1.685E+04	9.206E+06
1991	1.600E+06	1.836E+04	1.003E+07
1992	1.750E+06	1.980E+04	1.082E+07
1993	1.900E+06	2.117E+04	1.157E+07
1994	2.070E+06	2.278E+04	1.245E+07
1995	2.420E+06	2.712E+04	1.481E+07
1996	2.770E+06	3.124E+04	1.707E+07
1997	3.120E+06	3.516E+04	1.921E+07
1998	3.385E+06	3.757E+04	2.052E+07
1999	3.650E+06	3.986E+04	2.178E+07

Carbon dioxide generation predictions for domestic wastes using CAA parameters for south area of [redacted] Landfill : waste input period 1973 - 2000

Year	Refuse In Place (Mg)	Carbon Dioxide Emission Rate (Mg/yr)	(Cubic m/yr)
2000	3.800E+06	4.025E+04	2.199E+07
2001	3.800E+06	3.829E+04	2.092E+07
2002	3.800E+06	3.642E+04	1.990E+07
2003	3.800E+06	3.464E+04	1.893E+07
2004	3.800E+06	3.296E+04	1.800E+07
2005	3.800E+06	3.135E+04	1.713E+07
2006	3.800E+06	2.982E+04	1.629E+07
2007	3.800E+06	2.836E+04	1.550E+07
2008	3.800E+06	2.698E+04	1.474E+07
2009	3.800E+06	2.567E+04	1.402E+07
2010	3.800E+06	2.441E+04	1.334E+07
2011	3.800E+06	2.322E+04	1.269E+07
2012	3.800E+06	2.209E+04	1.207E+07
2013	3.800E+06	2.101E+04	1.148E+07
2014	3.800E+06	1.999E+04	1.092E+07
2015	3.800E+06	1.901E+04	1.039E+07
2016	3.800E+06	1.809E+04	9.880E+06
2017	3.800E+06	1.720E+04	9.399E+06
2018	3.800E+06	1.637E+04	8.940E+06
2019	3.800E+06	1.557E+04	8.504E+06
2020	3.800E+06	1.481E+04	8.089E+06
2021	3.800E+06	1.409E+04	7.695E+06
2022	3.800E+06	1.340E+04	7.320E+06
2023	3.800E+06	1.275E+04	6.963E+06
2024	3.800E+06	1.212E+04	6.623E+06
2025	3.800E+06	1.153E+04	6.300E+06
2026	3.800E+06	1.097E+04	5.993E+06
2027	3.800E+06	1.043E+04	5.701E+06
2028	3.800E+06	9.926E+03	5.423E+06
2029	3.800E+06	9.442E+03	5.158E+06
2030	3.800E+06	8.981E+03	4.906E+06
2031	3.800E+06	8.543E+03	4.667E+06
2032	3.800E+06	8.127E+03	4.440E+06
2033	3.800E+06	7.730E+03	4.223E+06
2034	3.800E+06	7.353E+03	4.017E+06
2035	3.800E+06	6.995E+03	3.821E+06
2036	3.800E+06	6.654E+03	3.635E+06
2037	3.800E+06	6.329E+03	3.458E+06
2038	3.800E+06	6.020E+03	3.289E+06
2039	3.800E+06	5.727E+03	3.129E+06
2040	3.800E+06	5.447E+03	2.976E+06

Carbon dioxide generation predictions for domestic wastes using CAA parameters for south area of [redacted] Landfill : waste input period 1973 - 2000

		Carbon Dioxide Emission Rate	
Year	Refuse In Place (Mg)	(Mg/yr)	(Cubic m/yr)
2041	3.800E+06	5.182E+03	2.831E+06
2042	3.800E+06	4.929E+03	2.693E+06
2043	3.800E+06	4.689E+03	2.561E+06
2044	3.800E+06	4.460E+03	2.436E+06
2045	3.800E+06	4.242E+03	2.318E+06
2046	3.800E+06	4.036E+03	2.205E+06
2047	3.800E+06	3.839E+03	2.097E+06
2048	3.800E+06	3.652E+03	1.995E+06
2049	3.800E+06	3.473E+03	1.898E+06
2050	3.800E+06	3.304E+03	1.805E+06
2051	3.800E+06	3.143E+03	1.717E+06
2052	3.800E+06	2.990E+03	1.633E+06
2053	3.800E+06	2.844E+03	1.554E+06
2054	3.800E+06	2.705E+03	1.478E+06
2055	3.800E+06	2.573E+03	1.406E+06
2056	3.800E+06	2.448E+03	1.337E+06
2057	3.800E+06	2.328E+03	1.272E+06
2058	3.800E+06	2.215E+03	1.210E+06
2059	3.800E+06	2.107E+03	1.151E+06
2060	3.800E+06	2.004E+03	1.095E+06
2061	3.800E+06	1.906E+03	1.041E+06
2062	3.800E+06	1.813E+03	9.906E+05
2063	3.800E+06	1.725E+03	9.423E+05
2064	3.800E+06	1.641E+03	8.963E+05
2065	3.800E+06	1.561E+03	8.526E+05
2066	3.800E+06	1.485E+03	8.110E+05
2067	3.800E+06	1.412E+03	7.715E+05
2068	3.800E+06	1.343E+03	7.339E+05
2069	3.800E+06	1.278E+03	6.981E+05
2070	3.800E+06	1.215E+03	6.640E+05
2071	3.800E+06	1.156E+03	6.316E+05
2072	3.800E+06	1.100E+03	6.008E+05
2073	3.800E+06	1.046E+03	5.715E+05
2074	3.800E+06	9.952E+02	5.437E+05
2075	3.800E+06	9.466E+02	5.171E+05
2076	3.800E+06	9.005E+02	4.919E+05
2077	3.800E+06	8.565E+02	4.679E+05
2078	3.800E+06	8.148E+02	4.451E+05
2079	3.800E+06	7.750E+02	4.234E+05
2080	3.800E+06	7.372E+02	4.027E+05
2081	3.800E+06	7.013E+02	3.831E+05

Carbon dioxide generation predictions for domestic wastes using CAA parameters for south area of [redacted] Landfill : waste input period 1973 - 2000

Year	Refuse In Place (Mg)	Carbon Dioxide Emission Rate (Mg/yr)	(Cubic m/yr)
2082	3.800E+06	6.671E+02	3.644E+05
2083	3.800E+06	6.345E+02	3.467E+05
2084	3.800E+06	6.036E+02	3.297E+05
2085	3.800E+06	5.742E+02	3.137E+05
2086	3.800E+06	5.462E+02	2.984E+05
2087	3.800E+06	5.195E+02	2.838E+05
2088	3.800E+06	4.942E+02	2.700E+05
2089	3.800E+06	4.701E+02	2.568E+05
2090	3.800E+06	4.472E+02	2.443E+05
2091	3.800E+06	4.253E+02	2.324E+05
2092	3.800E+06	4.046E+02	2.210E+05
2093	3.800E+06	3.849E+02	2.103E+05
2094	3.800E+06	3.661E+02	2.000E+05
2095	3.800E+06	3.482E+02	1.902E+05
2096	3.800E+06	3.313E+02	1.810E+05
2097	3.800E+06	3.151E+02	1.721E+05
2098	3.800E+06	2.997E+02	1.637E+05
2099	3.800E+06	2.851E+02	1.558E+05
2100	3.800E+06	2.712E+02	1.482E+05
2101	3.800E+06	2.580E+02	1.409E+05
2102	3.800E+06	2.454E+02	1.341E+05
2103	3.800E+06	2.334E+02	1.275E+05
2104	3.800E+06	2.221E+02	1.213E+05
2105	3.800E+06	2.112E+02	1.154E+05
2106	3.800E+06	2.009E+02	1.098E+05
2107	3.800E+06	1.911E+02	1.044E+05
2108	3.800E+06	1.818E+02	9.932E+04
2109	3.800E+06	1.729E+02	9.447E+04
2110	3.800E+06	1.645E+02	8.987E+04
2111	3.800E+06	1.565E+02	8.548E+04
2112	3.800E+06	1.488E+02	8.131E+04
2113	3.800E+06	1.416E+02	7.735E+04
2114	3.800E+06	1.347E+02	7.358E+04
2115	3.800E+06	1.281E+02	6.999E+04
2116	3.800E+06	1.219E+02	6.657E+04
2117	3.800E+06	1.159E+02	6.333E+04
2118	3.800E+06	1.103E+02	6.024E+04
2119	3.800E+06	1.049E+02	5.730E+04
2120	3.800E+06	9.977E+01	5.451E+04
2121	3.800E+06	9.491E+01	5.185E+04
2122	3.800E+06	9.028E+01	4.932E+04

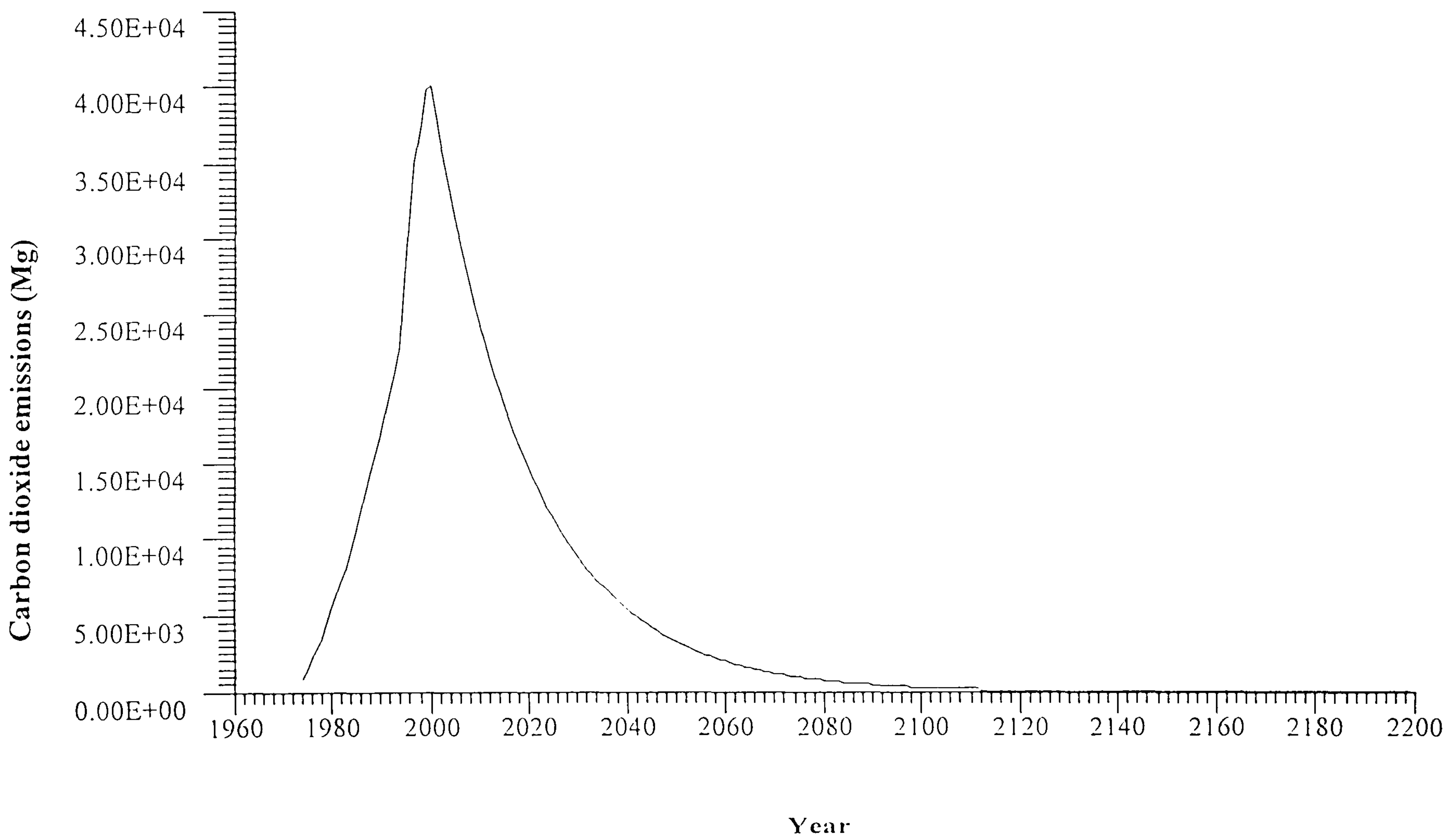
Carbon dioxide generation predictions for domestic wastes using CAA parameters for south area of [redacted] Landfill : waste input period 1973 - 2000

Year	Refuse In Place (Mg)	Carbon Dioxide Emission Rate (Mg/yr)	(Cubic m/yr)
2123	3.800E+06	8.588E+01	4.691E+04
2124	3.800E+06	8.169E+01	4.463E+04
2125	3.800E+06	7.770E+01	4.245E+04
2126	3.800E+06	7.391E+01	4.038E+04
2127	3.800E+06	7.031E+01	3.841E+04
2128	3.800E+06	6.688E+01	3.654E+04
2129	3.800E+06	6.362E+01	3.475E+04
2130	3.800E+06	6.052E+01	3.306E+04
2131	3.800E+06	5.756E+01	3.145E+04
2132	3.800E+06	5.476E+01	2.991E+04
2133	3.800E+06	5.209E+01	2.845E+04
2134	3.800E+06	4.955E+01	2.707E+04
2135	3.800E+06	4.713E+01	2.575E+04
2136	3.800E+06	4.483E+01	2.449E+04
2137	3.800E+06	4.264E+01	2.330E+04
2138	3.800E+06	4.056E+01	2.216E+04
2139	3.800E+06	3.859E+01	2.108E+04
2140	3.800E+06	3.670E+01	2.005E+04
2141	3.800E+06	3.491E+01	1.907E+04
2142	3.800E+06	3.321E+01	1.814E+04
2143	3.800E+06	3.159E+01	1.726E+04
2144	3.800E+06	3.005E+01	1.642E+04
2145	3.800E+06	2.859E+01	1.562E+04
2146	3.800E+06	2.719E+01	1.485E+04
2147	3.800E+06	2.587E+01	1.413E+04
2148	3.800E+06	2.460E+01	1.344E+04
2149	3.800E+06	2.340E+01	1.279E+04
2150	3.800E+06	2.226E+01	1.216E+04
2151	3.800E+06	2.118E+01	1.157E+04
2152	3.800E+06	2.014E+01	1.100E+04
2153	3.800E+06	1.916E+01	1.047E+04
2154	3.800E+06	1.823E+01	9.957E+03
2155	3.800E+06	1.734E+01	9.472E+03
2156	3.800E+06	1.649E+01	9.010E+03
2157	3.800E+06	1.569E+01	8.570E+03
2158	3.800E+06	1.492E+01	8.152E+03
2159	3.800E+06	1.420E+01	7.755E+03
2160	3.800E+06	1.350E+01	7.377E+03
2161	3.800E+06	1.284E+01	7.017E+03
2162	3.800E+06	1.222E+01	6.675E+03
2163	3.800E+06	1.162E+01	6.349E+03

Carbon dioxide generation predictions for domestic wastes using CAA parameters for south area of [redacted] Landfill : waste input period 1973 - 2000

		Carbon Dioxide Emission Rate	
Year	Refuse In Place (Mg)	(Mg/yr)	(Cubic m/yr)
2164	3.800E+06	1.106E+01	6.039E+03
2165	3.800E+06	1.052E+01	5.745E+03
2166	3.800E+06	1.000E+01	5.465E+03
2167	3.800E+06	9.515E+00	5.198E+03
2168	3.800E+06	9.051E+00	4.945E+03
2169	3.800E+06	8.610E+00	4.704E+03
2170	3.800E+06	8.190E+00	4.474E+03
2171	3.800E+06	7.790E+00	4.256E+03
2172	3.800E+06	7.411E+00	4.048E+03
2173	3.800E+06	7.049E+00	3.851E+03
2174	3.800E+06	6.705E+00	3.663E+03
2175	3.800E+06	6.378E+00	3.484E+03
2176	3.800E+06	6.067E+00	3.315E+03
2177	3.800E+06	5.771E+00	3.153E+03
2178	3.800E+06	5.490E+00	2.999E+03
2179	3.800E+06	5.222E+00	2.853E+03
2180	3.800E+06	4.967E+00	2.714E+03
2181	3.800E+06	4.725E+00	2.581E+03
2182	3.800E+06	4.495E+00	2.455E+03
2183	3.800E+06	4.276E+00	2.336E+03
2184	3.800E+06	4.067E+00	2.222E+03
2185	3.800E+06	3.869E+00	2.113E+03
2186	3.800E+06	3.680E+00	2.010E+03
2187	3.800E+06	3.500E+00	1.912E+03
2188	3.800E+06	3.330E+00	1.819E+03
2189	3.800E+06	3.167E+00	1.730E+03
2190	3.800E+06	3.013E+00	1.646E+03
2191	3.800E+06	2.866E+00	1.566E+03
2192	3.800E+06	2.726E+00	1.489E+03
2193	3.800E+06	2.593E+00	1.417E+03
2194	3.800E+06	2.467E+00	1.348E+03
2195	3.800E+06	2.346E+00	1.282E+03
2196	3.800E+06	2.232E+00	1.219E+03
2197	3.800E+06	2.123E+00	1.160E+03
2198	3.800E+06	2.020E+00	1.103E+03
2199	3.800E+06	1.921E+00	1.050E+03

Projected Carbon Dioxide Emissions for domestic waste using CAA parameters for south area of landfill



Methane generation predictions for domestic wastes using CAA parameters for south area of [redacted] Landfill : waste input period 1973 - 2000

Model Parameters

Lo : 170.00 m^3 / Mg
k : 0.0500 1/yr
NMOC : 4000.00 ppmv
Methane : 50.0000 % volume
Carbon Dioxide : 50.0000 % volume

Landfill Parameters

Landfill type : No Co-Disposal
Year Opened : 1973 Current Year : 2000 Closure Year: 2000
Capacity : 3800000 Mg
Average Acceptance Rate Required from
Current Year to Closure Year : 0.00 Mg/year

Model Results

Year	Refuse In Place (Mg)	Methane Emission Rate (Mg/yr)	Methane Emission Rate (Cubic m/yr)
1974	5.000E+04	2.835E+02	4.250E+05
1975	1.000E+05	5.532E+02	8.293E+05
1976	1.500E+05	8.098E+02	1.214E+06
1977	2.000E+05	1.054E+03	1.580E+06
1978	2.500E+05	1.286E+03	1.928E+06
1979	3.250E+05	1.649E+03	2.471E+06
1980	4.000E+05	1.993E+03	2.988E+06
1981	4.750E+05	2.322E+03	3.480E+06
1982	5.500E+05	2.634E+03	3.948E+06
1983	6.250E+05	2.931E+03	4.393E+06
1984	7.250E+05	3.355E+03	5.028E+06
1985	8.250E+05	3.758E+03	5.633E+06
1986	9.500E+05	4.284E+03	6.421E+06
1987	1.075E+06	4.784E+03	7.170E+06
1988	1.200E+06	5.259E+03	7.883E+06
1989	1.325E+06	5.712E+03	8.561E+06
1990	1.450E+06	6.142E+03	9.206E+06
1991	1.600E+06	6.693E+03	1.003E+07
1992	1.750E+06	7.217E+03	1.082E+07
1993	1.900E+06	7.716E+03	1.157E+07
1994	2.070E+06	8.303E+03	1.245E+07
1995	2.420E+06	9.883E+03	1.481E+07
1996	2.770E+06	1.139E+04	1.707E+07
1997	3.120E+06	1.282E+04	1.921E+07
1998	3.385E+06	1.369E+04	2.052E+07
1999	3.650E+06	1.453E+04	2.178E+07

Methane generation predictions for domestic wastes using CAA parameters for south area of [redacted] Landfill : waste input period 1973 - 2000

Year	Refuse In Place (Mg)	Methane Emission Rate (Mg/yr)	Methane Emission Rate (Cubic m/yr)
2000	3.800E+06	1.467E+04	2.199E+07
2001	3.800E+06	1.395E+04	2.092E+07
2002	3.800E+06	1.327E+04	1.990E+07
2003	3.800E+06	1.263E+04	1.893E+07
2004	3.800E+06	1.201E+04	1.800E+07
2005	3.800E+06	1.143E+04	1.713E+07
2006	3.800E+06	1.087E+04	1.629E+07
2007	3.800E+06	1.034E+04	1.550E+07
2008	3.800E+06	9.834E+03	1.474E+07
2009	3.800E+06	9.354E+03	1.402E+07
2010	3.800E+06	8.898E+03	1.334E+07
2011	3.800E+06	8.464E+03	1.269E+07
2012	3.800E+06	8.051E+03	1.207E+07
2013	3.800E+06	7.659E+03	1.148E+07
2014	3.800E+06	7.285E+03	1.092E+07
2015	3.800E+06	6.930E+03	1.039E+07
2016	3.800E+06	6.592E+03	9.880E+06
2017	3.800E+06	6.270E+03	9.399E+06
2018	3.800E+06	5.964E+03	8.940E+06
2019	3.800E+06	5.674E+03	8.504E+06
2020	3.800E+06	5.397E+03	8.089E+06
2021	3.800E+06	5.134E+03	7.695E+06
2022	3.800E+06	4.883E+03	7.320E+06
2023	3.800E+06	4.645E+03	6.963E+06
2024	3.800E+06	4.419E+03	6.623E+06
2025	3.800E+06	4.203E+03	6.300E+06
2026	3.800E+06	3.998E+03	5.993E+06
2027	3.800E+06	3.803E+03	5.701E+06
2028	3.800E+06	3.618E+03	5.423E+06
2029	3.800E+06	3.441E+03	5.158E+06
2030	3.800E+06	3.273E+03	4.906E+06
2031	3.800E+06	3.114E+03	4.667E+06
2032	3.800E+06	2.962E+03	4.440E+06
2033	3.800E+06	2.817E+03	4.223E+06
2034	3.800E+06	2.680E+03	4.017E+06
2035	3.800E+06	2.549E+03	3.821E+06
2036	3.800E+06	2.425E+03	3.635E+06
2037	3.800E+06	2.307E+03	3.458E+06
2038	3.800E+06	2.194E+03	3.289E+06
2039	3.800E+06	2.087E+03	3.129E+06
2040	3.800E+06	1.985E+03	2.976E+06

Methane generation predictions for domestic wastes using CAA parameters for south area of [redacted] Landfill : waste input period 1973 - 2000

Year	Refuse In Place (Mg)	Methane Emission Rate (Mg/yr)	(Cubic m/yr)
2041	3.800E+06	1.889E+03	2.831E+06
2042	3.800E+06	1.796E+03	2.693E+06
2043	3.800E+06	1.709E+03	2.561E+06
2044	3.800E+06	1.626E+03	2.436E+06
2045	3.800E+06	1.546E+03	2.318E+06
2046	3.800E+06	1.471E+03	2.205E+06
2047	3.800E+06	1.399E+03	2.097E+06
2048	3.800E+06	1.331E+03	1.995E+06
2049	3.800E+06	1.266E+03	1.898E+06
2050	3.800E+06	1.204E+03	1.805E+06
2051	3.800E+06	1.145E+03	1.717E+06
2052	3.800E+06	1.090E+03	1.633E+06
2053	3.800E+06	1.036E+03	1.554E+06
2054	3.800E+06	9.859E+02	1.478E+06
2055	3.800E+06	9.378E+02	1.406E+06
2056	3.800E+06	8.921E+02	1.337E+06
2057	3.800E+06	8.486E+02	1.272E+06
2058	3.800E+06	8.072E+02	1.210E+06
2059	3.800E+06	7.678E+02	1.151E+06
2060	3.800E+06	7.304E+02	1.095E+06
2061	3.800E+06	6.948E+02	1.041E+06
2062	3.800E+06	6.609E+02	9.906E+05
2063	3.800E+06	6.286E+02	9.423E+05
2064	3.800E+06	5.980E+02	8.963E+05
2065	3.800E+06	5.688E+02	8.526E+05
2066	3.800E+06	5.411E+02	8.110E+05
2067	3.800E+06	5.147E+02	7.715E+05
2068	3.800E+06	4.896E+02	7.339E+05
2069	3.800E+06	4.657E+02	6.981E+05
2070	3.800E+06	4.430E+02	6.640E+05
2071	3.800E+06	4.214E+02	6.316E+05
2072	3.800E+06	4.008E+02	6.008E+05
2073	3.800E+06	3.813E+02	5.715E+05
2074	3.800E+06	3.627E+02	5.437E+05
2075	3.800E+06	3.450E+02	5.171E+05
2076	3.800E+06	3.282E+02	4.919E+05
2077	3.800E+06	3.122E+02	4.679E+05
2078	3.800E+06	2.970E+02	4.451E+05
2079	3.800E+06	2.825E+02	4.234E+05
2080	3.800E+06	2.687E+02	4.027E+05
2081	3.800E+06	2.556E+02	3.831E+05

Methane generation predictions for domestic wastes using CAA parameters for south area of [redacted] Landfill : waste input period 1973 - 2000

Year	Refuse In Place (Mg)	Methane Emission Rate (Mg/yr)	(Cubic m/yr)
2082	3.800E+06	2.431E+02	3.644E+05
2083	3.800E+06	2.313E+02	3.467E+05
2084	3.800E+06	2.200E+02	3.297E+05
2085	3.800E+06	2.093E+02	3.137E+05
2086	3.800E+06	1.991E+02	2.984E+05
2087	3.800E+06	1.893E+02	2.838E+05
2088	3.800E+06	1.801E+02	2.700E+05
2089	3.800E+06	1.713E+02	2.568E+05
2090	3.800E+06	1.630E+02	2.443E+05
2091	3.800E+06	1.550E+02	2.324E+05
2092	3.800E+06	1.475E+02	2.210E+05
2093	3.800E+06	1.403E+02	2.103E+05
2094	3.800E+06	1.334E+02	2.000E+05
2095	3.800E+06	1.269E+02	1.902E+05
2096	3.800E+06	1.207E+02	1.810E+05
2097	3.800E+06	1.148E+02	1.721E+05
2098	3.800E+06	1.092E+02	1.637E+05
2099	3.800E+06	1.039E+02	1.558E+05
2100	3.800E+06	9.885E+01	1.482E+05
2101	3.800E+06	9.403E+01	1.409E+05
2102	3.800E+06	8.944E+01	1.341E+05
2103	3.800E+06	8.508E+01	1.275E+05
2104	3.800E+06	8.093E+01	1.213E+05
2105	3.800E+06	7.698E+01	1.154E+05
2106	3.800E+06	7.323E+01	1.098E+05
2107	3.800E+06	6.966E+01	1.044E+05
2108	3.800E+06	6.626E+01	9.932E+04
2109	3.800E+06	6.303E+01	9.447E+04
2110	3.800E+06	5.995E+01	8.987E+04
2111	3.800E+06	5.703E+01	8.548E+04
2112	3.800E+06	5.425E+01	8.131E+04
2113	3.800E+06	5.160E+01	7.735E+04
2114	3.800E+06	4.909E+01	7.358E+04
2115	3.800E+06	4.669E+01	6.999E+04
2116	3.800E+06	4.441E+01	6.657E+04
2117	3.800E+06	4.225E+01	6.333E+04
2118	3.800E+06	4.019E+01	6.024E+04
2119	3.800E+06	3.823E+01	5.730E+04
2120	3.800E+06	3.636E+01	5.451E+04
2121	3.800E+06	3.459E+01	5.185E+04
2122	3.800E+06	3.290E+01	4.932E+04

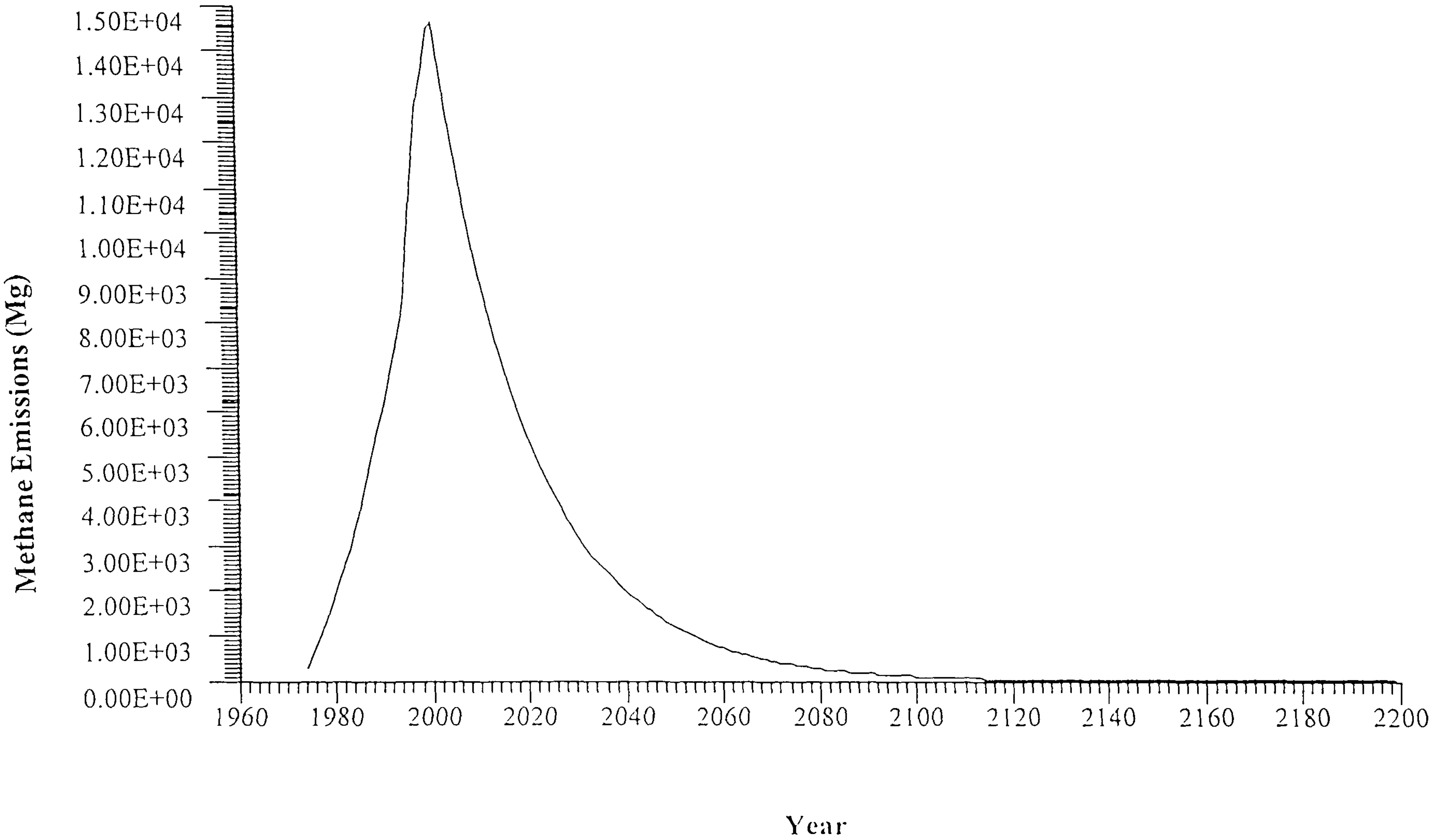
Methane generation predictions for domestic wastes using CAA parameters for south area of [redacted] Landfill : waste input period 1973 - 2000

Year	Refuse In Place (Mg)	Methane Emission Rate (Mg/yr)	(Cubic m/yr)
2123	3.800E+06	3.130E+01	4.691E+04
2124	3.800E+06	2.977E+01	4.463E+04
2125	3.800E+06	2.832E+01	4.245E+04
2126	3.800E+06	2.694E+01	4.038E+04
2127	3.800E+06	2.563E+01	3.841E+04
2128	3.800E+06	2.438E+01	3.654E+04
2129	3.800E+06	2.319E+01	3.475E+04
2130	3.800E+06	2.206E+01	3.306E+04
2131	3.800E+06	2.098E+01	3.145E+04
2132	3.800E+06	1.996E+01	2.991E+04
2133	3.800E+06	1.898E+01	2.845E+04
2134	3.800E+06	1.806E+01	2.707E+04
2135	3.800E+06	1.718E+01	2.575E+04
2136	3.800E+06	1.634E+01	2.449E+04
2137	3.800E+06	1.554E+01	2.330E+04
2138	3.800E+06	1.478E+01	2.216E+04
2139	3.800E+06	1.406E+01	2.108E+04
2140	3.800E+06	1.338E+01	2.005E+04
2141	3.800E+06	1.273E+01	1.907E+04
2142	3.800E+06	1.210E+01	1.814E+04
2143	3.800E+06	1.151E+01	1.726E+04
2144	3.800E+06	1.095E+01	1.642E+04
2145	3.800E+06	1.042E+01	1.562E+04
2146	3.800E+06	9.910E+00	1.485E+04
2147	3.800E+06	9.427E+00	1.413E+04
2148	3.800E+06	8.967E+00	1.344E+04
2149	3.800E+06	8.530E+00	1.279E+04
2150	3.800E+06	8.114E+00	1.216E+04
2151	3.800E+06	7.718E+00	1.157E+04
2152	3.800E+06	7.342E+00	1.100E+04
2153	3.800E+06	6.984E+00	1.047E+04
2154	3.800E+06	6.643E+00	9.957E+03
2155	3.800E+06	6.319E+00	9.472E+03
2156	3.800E+06	6.011E+00	9.010E+03
2157	3.800E+06	5.718E+00	8.570E+03
2158	3.800E+06	5.439E+00	8.152E+03
2159	3.800E+06	5.174E+00	7.755E+03
2160	3.800E+06	4.921E+00	7.377E+03
2161	3.800E+06	4.681E+00	7.017E+03
2162	3.800E+06	4.453E+00	6.675E+03
2163	3.800E+06	4.236E+00	6.349E+03

Methane generation predictions for domestic wastes using CAA parameters for south area of [redacted] Landfill : waste input period 1973 - 2000

Year	Refuse In Place (Mg)	Methane Emission Rate (Mg/yr)	(Cubic m/yr)
2164	3.800E+06	4.029E+00	6.039E+03
2165	3.800E+06	3.833E+00	5.745E+03
2166	3.800E+06	3.646E+00	5.465E+03
2167	3.800E+06	3.468E+00	5.198E+03
2168	3.800E+06	3.299E+00	4.945E+03
2169	3.800E+06	3.138E+00	4.704E+03
2170	3.800E+06	2.985E+00	4.474E+03
2171	3.800E+06	2.839E+00	4.256E+03
2172	3.800E+06	2.701E+00	4.048E+03
2173	3.800E+06	2.569E+00	3.851E+03
2174	3.800E+06	2.444E+00	3.663E+03
2175	3.800E+06	2.325E+00	3.484E+03
2176	3.800E+06	2.211E+00	3.315E+03
2177	3.800E+06	2.103E+00	3.153E+03
2178	3.800E+06	2.001E+00	2.999E+03
2179	3.800E+06	1.903E+00	2.853E+03
2180	3.800E+06	1.810E+00	2.714E+03
2181	3.800E+06	1.722E+00	2.581E+03
2182	3.800E+06	1.638E+00	2.455E+03
2183	3.800E+06	1.558E+00	2.336E+03
2184	3.800E+06	1.482E+00	2.222E+03
2185	3.800E+06	1.410E+00	2.113E+03
2186	3.800E+06	1.341E+00	2.010E+03
2187	3.800E+06	1.276E+00	1.912E+03
2188	3.800E+06	1.214E+00	1.819E+03
2189	3.800E+06	1.154E+00	1.730E+03
2190	3.800E+06	1.098E+00	1.646E+03
2191	3.800E+06	1.045E+00	1.566E+03
2192	3.800E+06	9.936E-01	1.489E+03
2193	3.800E+06	9.451E-01	1.417E+03
2194	3.800E+06	8.990E-01	1.348E+03
2195	3.800E+06	8.552E-01	1.282E+03
2196	3.800E+06	8.135E-01	1.219E+03
2197	3.800E+06	7.738E-01	1.160E+03
2198	3.800E+06	7.361E-01	1.103E+03
2199	3.800E+06	7.002E-01	1.050E+03

Projected Methane Emissions for domestic waste using CAA parameters for south area of landfill



APPENDIX C

Model 1A - [redacted]South (Co-disposal - no adjustment for inerts)

Methane generation predictions for co-disposal wastes using CAA parameters for south area of [redacted] Landfill : waste input period 1973 - 2000

Model Parameters

Lo : 170.00 m^3 / Mg
k : 0.0500 1/yr
NMOC : 4000.00 ppmv
Methane : 50.0000 % volume
Carbon Dioxide : 50.0000 % volume

Landfill Parameters

Landfill type : Co-Disposal
Year Opened : 1973 Current Year : 2000 Closure Year: 2000
Capacity : 3800000 Mg
Average Acceptance Rate Required from
Current Year to Closure Year : 0.00 Mg/year

Model Results

		Methane Emission Rate	
Year	Refuse In Place (Mg)	(Mg/yr)	(Cubic m/yr)
1974	5.000E+04	2.835E+02	4.250E+05
1975	1.000E+05	5.532E+02	8.293E+05
1976	1.500E+05	8.098E+02	1.214E+06
1977	2.000E+05	1.054E+03	1.580E+06
1978	2.500E+05	1.286E+03	1.928E+06
1979	3.250E+05	1.649E+03	2.471E+06
1980	4.000E+05	1.993E+03	2.988E+06
1981	4.750E+05	2.322E+03	3.480E+06
1982	5.500E+05	2.634E+03	3.948E+06
1983	6.250E+05	2.931E+03	4.393E+06
1984	7.250E+05	3.355E+03	5.028E+06
1985	8.250E+05	3.758E+03	5.633E+06
1986	9.500E+05	4.284E+03	6.421E+06
1987	1.075E+06	4.784E+03	7.170E+06
1988	1.200E+06	5.259E+03	7.883E+06
1989	1.325E+06	5.712E+03	8.561E+06
1990	1.450E+06	6.142E+03	9.206E+06
1991	1.600E+06	6.693E+03	1.003E+07
1992	1.750E+06	7.217E+03	1.082E+07
1993	1.900E+06	7.716E+03	1.157E+07
1994	2.070E+06	8.303E+03	1.245E+07
1995	2.420E+06	9.883E+03	1.481E+07
1996	2.770E+06	1.139E+04	1.707E+07
1997	3.120E+06	1.282E+04	1.921E+07
1998	3.385E+06	1.369E+04	2.052E+07

Methane generation predictions for co-disposal wastes using CAA parameters for south area of [redacted] Landfill : waste input period 1973 - 2000

Year	Refuse In Place (Mg)	Methane Emission Rate (Mg/yr)	(Cubic m/yr)
1999	3.650E+06	1.453E+04	2.178E+07
2000	3.800E+06	1.467E+04	2.199E+07
2001	3.800E+06	1.395E+04	2.092E+07
2002	3.800E+06	1.327E+04	1.990E+07
2003	3.800E+06	1.263E+04	1.893E+07
2004	3.800E+06	1.201E+04	1.800E+07
2005	3.800E+06	1.143E+04	1.713E+07
2006	3.800E+06	1.087E+04	1.629E+07
2007	3.800E+06	1.034E+04	1.550E+07
2008	3.800E+06	9.834E+03	1.474E+07
2009	3.800E+06	9.354E+03	1.402E+07
2010	3.800E+06	8.898E+03	1.334E+07
2011	3.800E+06	8.464E+03	1.269E+07
2012	3.800E+06	8.051E+03	1.207E+07
2013	3.800E+06	7.659E+03	1.148E+07
2014	3.800E+06	7.285E+03	1.092E+07
2015	3.800E+06	6.930E+03	1.039E+07
2016	3.800E+06	6.592E+03	9.880E+06
2017	3.800E+06	6.270E+03	9.399E+06
2018	3.800E+06	5.964E+03	8.940E+06
2019	3.800E+06	5.674E+03	8.504E+06
2020	3.800E+06	5.397E+03	8.089E+06
2021	3.800E+06	5.134E+03	7.695E+06
2022	3.800E+06	4.883E+03	7.320E+06
2023	3.800E+06	4.645E+03	6.963E+06
2024	3.800E+06	4.419E+03	6.623E+06
2025	3.800E+06	4.203E+03	6.300E+06
2026	3.800E+06	3.998E+03	5.993E+06
2027	3.800E+06	3.803E+03	5.701E+06
2028	3.800E+06	3.618E+03	5.423E+06
2029	3.800E+06	3.441E+03	5.158E+06
2030	3.800E+06	3.273E+03	4.906E+06
2031	3.800E+06	3.114E+03	4.667E+06
2032	3.800E+06	2.962E+03	4.440E+06
2033	3.800E+06	2.817E+03	4.223E+06
2034	3.800E+06	2.680E+03	4.017E+06
2035	3.800E+06	2.549E+03	3.821E+06
2036	3.800E+06	2.425E+03	3.635E+06
2037	3.800E+06	2.307E+03	3.458E+06
2038	3.800E+06	2.194E+03	3.289E+06
2039	3.800E+06	2.087E+03	3.129E+06

Methane generation predictions for co-disposal wastes using CAA parameters for south area of [redacted] Landfill : waste input period 1973 - 2000

		Methane Emission Rate	
Year	Refuse In Place (Mg)	(Mg/yr)	(Cubic m/yr)
2040	3.800E+06	1.985E+03	2.976E+06
2041	3.800E+06	1.889E+03	2.831E+06
2042	3.800E+06	1.796E+03	2.693E+06
2043	3.800E+06	1.709E+03	2.561E+06
2044	3.800E+06	1.626E+03	2.436E+06
2045	3.800E+06	1.546E+03	2.318E+06
2046	3.800E+06	1.471E+03	2.205E+06
2047	3.800E+06	1.399E+03	2.097E+06
2048	3.800E+06	1.331E+03	1.995E+06
2049	3.800E+06	1.266E+03	1.898E+06
2050	3.800E+06	1.204E+03	1.805E+06
2051	3.800E+06	1.145E+03	1.717E+06
2052	3.800E+06	1.090E+03	1.633E+06
2053	3.800E+06	1.036E+03	1.554E+06
2054	3.800E+06	9.859E+02	1.478E+06
2055	3.800E+06	9.378E+02	1.406E+06
2056	3.800E+06	8.921E+02	1.337E+06
2057	3.800E+06	8.486E+02	1.272E+06
2058	3.800E+06	8.072E+02	1.210E+06
2059	3.800E+06	7.678E+02	1.151E+06
2060	3.800E+06	7.304E+02	1.095E+06
2061	3.800E+06	6.948E+02	1.041E+06
2062	3.800E+06	6.609E+02	9.906E+05
2063	3.800E+06	6.286E+02	9.423E+05
2064	3.800E+06	5.980E+02	8.963E+05
2065	3.800E+06	5.688E+02	8.526E+05
2066	3.800E+06	5.411E+02	8.110E+05
2067	3.800E+06	5.147E+02	7.715E+05
2068	3.800E+06	4.896E+02	7.339E+05
2069	3.800E+06	4.657E+02	6.981E+05
2070	3.800E+06	4.430E+02	6.640E+05
2071	3.800E+06	4.214E+02	6.316E+05
2072	3.800E+06	4.008E+02	6.008E+05
2073	3.800E+06	3.813E+02	5.715E+05
2074	3.800E+06	3.627E+02	5.437E+05
2075	3.800E+06	3.450E+02	5.171E+05
2076	3.800E+06	3.282E+02	4.919E+05
2077	3.800E+06	3.122E+02	4.679E+05
2078	3.800E+06	2.970E+02	4.451E+05
2079	3.800E+06	2.825E+02	4.234E+05
2080	3.800E+06	2.687E+02	4.027E+05

Methane generation predictions for co-disposal wastes using CAA parameters for south area of [redacted] Landfill : waste input period 1973 - 2000

Year	Refuse In Place (Mg)	Methane Emission Rate (Mg/yr)	Methane Emission Rate (Cubic m/yr)
2081	3.800E+06	2.556E+02	3.831E+05
2082	3.800E+06	2.431E+02	3.644E+05
2083	3.800E+06	2.313E+02	3.467E+05
2084	3.800E+06	2.200E+02	3.297E+05
2085	3.800E+06	2.093E+02	3.137E+05
2086	3.800E+06	1.991E+02	2.984E+05
2087	3.800E+06	1.893E+02	2.838E+05
2088	3.800E+06	1.801E+02	2.700E+05
2089	3.800E+06	1.713E+02	2.568E+05
2090	3.800E+06	1.630E+02	2.443E+05
2091	3.800E+06	1.550E+02	2.324E+05
2092	3.800E+06	1.475E+02	2.210E+05
2093	3.800E+06	1.403E+02	2.103E+05
2094	3.800E+06	1.334E+02	2.000E+05
2095	3.800E+06	1.269E+02	1.902E+05
2096	3.800E+06	1.207E+02	1.810E+05
2097	3.800E+06	1.148E+02	1.721E+05
2098	3.800E+06	1.092E+02	1.637E+05
2099	3.800E+06	1.039E+02	1.558E+05
2100	3.800E+06	9.885E+01	1.482E+05
2101	3.800E+06	9.403E+01	1.409E+05
2102	3.800E+06	8.944E+01	1.341E+05
2103	3.800E+06	8.508E+01	1.275E+05
2104	3.800E+06	8.093E+01	1.213E+05
2105	3.800E+06	7.698E+01	1.154E+05
2106	3.800E+06	7.323E+01	1.098E+05
2107	3.800E+06	6.966E+01	1.044E+05
2108	3.800E+06	6.626E+01	9.932E+04
2109	3.800E+06	6.303E+01	9.447E+04
2110	3.800E+06	5.995E+01	8.987E+04
2111	3.800E+06	5.703E+01	8.548E+04
2112	3.800E+06	5.425E+01	8.131E+04
2113	3.800E+06	5.160E+01	7.735E+04
2114	3.800E+06	4.909E+01	7.358E+04
2115	3.800E+06	4.669E+01	6.999E+04
2116	3.800E+06	4.441E+01	6.657E+04
2117	3.800E+06	4.225E+01	6.333E+04
2118	3.800E+06	4.019E+01	6.024E+04
2119	3.800E+06	3.823E+01	5.730E+04
2120	3.800E+06	3.636E+01	5.451E+04
2121	3.800E+06	3.459E+01	5.185E+04

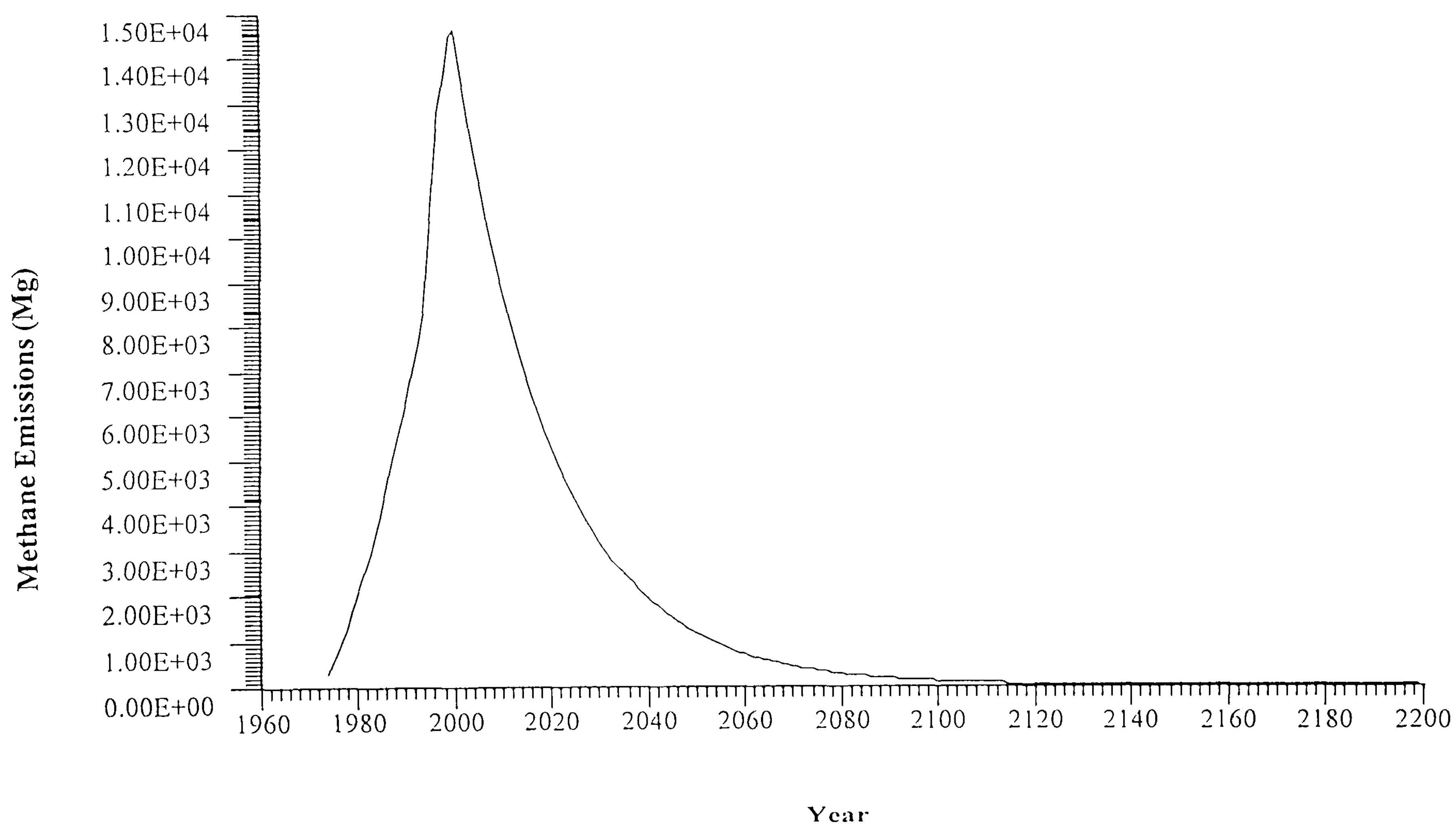
Methane generation predictions for co-disposal wastes using CAA parameters for south area of [redacted] Landfill : waste input period 1973 - 2000

Year	Refuse In Place (Mg)	Methane Emission Rate (Mg/yr)	(Cubic m/yr)
2122	3.800E+06	3.290E+01	4.932E+04
2123	3.800E+06	3.130E+01	4.691E+04
2124	3.800E+06	2.977E+01	4.463E+04
2125	3.800E+06	2.832E+01	4.245E+04
2126	3.800E+06	2.694E+01	4.038E+04
2127	3.800E+06	2.563E+01	3.841E+04
2128	3.800E+06	2.438E+01	3.654E+04
2129	3.800E+06	2.319E+01	3.475E+04
2130	3.800E+06	2.206E+01	3.306E+04
2131	3.800E+06	2.098E+01	3.145E+04
2132	3.800E+06	1.996E+01	2.991E+04
2133	3.800E+06	1.898E+01	2.845E+04
2134	3.800E+06	1.806E+01	2.707E+04
2135	3.800E+06	1.718E+01	2.575E+04
2136	3.800E+06	1.634E+01	2.449E+04
2137	3.800E+06	1.554E+01	2.330E+04
2138	3.800E+06	1.478E+01	2.216E+04
2139	3.800E+06	1.406E+01	2.108E+04
2140	3.800E+06	1.338E+01	2.005E+04
2141	3.800E+06	1.273E+01	1.907E+04
2142	3.800E+06	1.210E+01	1.814E+04
2143	3.800E+06	1.151E+01	1.726E+04
2144	3.800E+06	1.095E+01	1.642E+04
2145	3.800E+06	1.042E+01	1.562E+04
2146	3.800E+06	9.910E+00	1.485E+04
2147	3.800E+06	9.427E+00	1.413E+04
2148	3.800E+06	8.967E+00	1.344E+04
2149	3.800E+06	8.530E+00	1.279E+04
2150	3.800E+06	8.114E+00	1.216E+04
2151	3.800E+06	7.718E+00	1.157E+04
2152	3.800E+06	7.342E+00	1.100E+04
2153	3.800E+06	6.984E+00	1.047E+04
2154	3.800E+06	6.643E+00	9.957E+03
2155	3.800E+06	6.319E+00	9.472E+03
2156	3.800E+06	6.011E+00	9.010E+03
2157	3.800E+06	5.718E+00	8.570E+03
2158	3.800E+06	5.439E+00	8.152E+03
2159	3.800E+06	5.174E+00	7.755E+03
2160	3.800E+06	4.921E+00	7.377E+03
2161	3.800E+06	4.681E+00	7.017E+03
2162	3.800E+06	4.453E+00	6.675E+03

Methane generation predictions for co-disposal wastes using CAA parameters for south area of [redacted] Landfill : waste input period 1973 - 2000

Year	Refuse In Place (Mg)	Methane Emission Rate (Mg/yr)	(Cubic m/yr)
2163	3.800E+06	4.236E+00	6.349E+03
2164	3.800E+06	4.029E+00	6.039E+03
2165	3.800E+06	3.833E+00	5.745E+03
2166	3.800E+06	3.646E+00	5.465E+03
2167	3.800E+06	3.468E+00	5.198E+03
2168	3.800E+06	3.299E+00	4.945E+03
2169	3.800E+06	3.138E+00	4.704E+03
2170	3.800E+06	2.985E+00	4.474E+03
2171	3.800E+06	2.839E+00	4.256E+03
2172	3.800E+06	2.701E+00	4.048E+03
2173	3.800E+06	2.569E+00	3.851E+03
2174	3.800E+06	2.444E+00	3.663E+03
2175	3.800E+06	2.325E+00	3.484E+03
2176	3.800E+06	2.211E+00	3.315E+03
2177	3.800E+06	2.103E+00	3.153E+03
2178	3.800E+06	2.001E+00	2.999E+03
2179	3.800E+06	1.903E+00	2.853E+03
2180	3.800E+06	1.810E+00	2.714E+03
2181	3.800E+06	1.722E+00	2.581E+03
2182	3.800E+06	1.638E+00	2.455E+03
2183	3.800E+06	1.558E+00	2.336E+03
2184	3.800E+06	1.482E+00	2.222E+03
2185	3.800E+06	1.410E+00	2.113E+03
2186	3.800E+06	1.341E+00	2.010E+03
2187	3.800E+06	1.276E+00	1.912E+03
2188	3.800E+06	1.214E+00	1.819E+03
2189	3.800E+06	1.154E+00	1.730E+03
2190	3.800E+06	1.098E+00	1.646E+03
2191	3.800E+06	1.045E+00	1.566E+03
2192	3.800E+06	9.936E-01	1.489E+03
2193	3.800E+06	9.451E-01	1.417E+03
2194	3.800E+06	8.990E-01	1.348E+03
2195	3.800E+06	8.552E-01	1.282E+03
2196	3.800E+06	8.135E-01	1.219E+03
2197	3.800E+06	7.738E-01	1.160E+03
2198	3.800E+06	7.361E-01	1.103E+03
2199	3.800E+06	7.002E-01	1.050E+03

Projected Methane Emissions for co-disposal using CAA parameters for south area of landfill



Carbon dioxide generation predictions for co-disposal wastes using CAA parameters for south area of [redacted] Landfill : waste input period 1973 - 2000

Model Parameters

Lo : 170.00 m^3 / Mg
k : 0.0500 1/yr
NMOC : 4000.00 ppmv
Methane : 50.0000 % volume
Carbon Dioxide : 50.0000 % volume

Landfill Parameters

Landfill type : Co-Disposal
Year Opened : 1973 Current Year : 2000 Closure Year: 2000
Capacity : 3800000 Mg
Average Acceptance Rate Required from
Current Year to Closure Year : 0.00 Mg/year

Model Results

Year	Refuse In Place (Mg)	Carbon Dioxide Emission Rate (Mg/yr)	(Cubic m/yr)
1974	5.000E+04	7.780E+02	4.250E+05
1975	1.000E+05	1.518E+03	8.293E+05
1976	1.500E+05	2.222E+03	1.214E+06
1977	2.000E+05	2.892E+03	1.580E+06
1978	2.500E+05	3.528E+03	1.928E+06
1979	3.250E+05	4.523E+03	2.471E+06
1980	4.000E+05	5.470E+03	2.988E+06
1981	4.750E+05	6.370E+03	3.480E+06
1982	5.500E+05	7.226E+03	3.948E+06
1983	6.250E+05	8.041E+03	4.393E+06
1984	7.250E+05	9.204E+03	5.028E+06
1985	8.250E+05	1.031E+04	5.633E+06
1986	9.500E+05	1.175E+04	6.421E+06
1987	1.075E+06	1.313E+04	7.170E+06
1988	1.200E+06	1.443E+04	7.883E+06
1989	1.325E+06	1.567E+04	8.561E+06
1990	1.450E+06	1.685E+04	9.206E+06
1991	1.600E+06	1.836E+04	1.003E+07
1992	1.750E+06	1.980E+04	1.082E+07
1993	1.900E+06	2.117E+04	1.157E+07
1994	2.070E+06	2.278E+04	1.245E+07
1995	2.420E+06	2.712E+04	1.481E+07
1996	2.770E+06	3.124E+04	1.707E+07
1997	3.120E+06	3.516E+04	1.921E+07
1998	3.385E+06	3.757E+04	2.052E+07
1999	3.650E+06	3.986E+04	2.178E+07

Carbon dioxide generation predictions for co-disposal wastes using CAA parameters for south area of [redacted] Landfill : waste input period 1973 - 2000

Year	Refuse In Place (Mg)	Carbon Dioxide Emission Rate (Mg/yr)	(Cubic m/yr)
2000	3.800E+06	4.025E+04	2.199E+07
2001	3.800E+06	3.829E+04	2.092E+07
2002	3.800E+06	3.642E+04	1.990E+07
2003	3.800E+06	3.464E+04	1.893E+07
2004	3.800E+06	3.296E+04	1.800E+07
2005	3.800E+06	3.135E+04	1.713E+07
2006	3.800E+06	2.982E+04	1.629E+07
2007	3.800E+06	2.836E+04	1.550E+07
2008	3.800E+06	2.698E+04	1.474E+07
2009	3.800E+06	2.567E+04	1.402E+07
2010	3.800E+06	2.441E+04	1.334E+07
2011	3.800E+06	2.322E+04	1.269E+07
2012	3.800E+06	2.209E+04	1.207E+07
2013	3.800E+06	2.101E+04	1.148E+07
2014	3.800E+06	1.999E+04	1.092E+07
2015	3.800E+06	1.901E+04	1.039E+07
2016	3.800E+06	1.809E+04	9.880E+06
2017	3.800E+06	1.720E+04	9.399E+06
2018	3.800E+06	1.637E+04	8.940E+06
2019	3.800E+06	1.557E+04	8.504E+06
2020	3.800E+06	1.481E+04	8.089E+06
2021	3.800E+06	1.409E+04	7.695E+06
2022	3.800E+06	1.340E+04	7.320E+06
2023	3.800E+06	1.275E+04	6.963E+06
2024	3.800E+06	1.212E+04	6.623E+06
2025	3.800E+06	1.153E+04	6.300E+06
2026	3.800E+06	1.097E+04	5.993E+06
2027	3.800E+06	1.043E+04	5.701E+06
2028	3.800E+06	9.926E+03	5.423E+06
2029	3.800E+06	9.442E+03	5.158E+06
2030	3.800E+06	8.981E+03	4.906E+06
2031	3.800E+06	8.543E+03	4.667E+06
2032	3.800E+06	8.127E+03	4.440E+06
2033	3.800E+06	7.730E+03	4.223E+06
2034	3.800E+06	7.353E+03	4.017E+06
2035	3.800E+06	6.995E+03	3.821E+06
2036	3.800E+06	6.654E+03	3.635E+06
2037	3.800E+06	6.329E+03	3.458E+06
2038	3.800E+06	6.020E+03	3.289E+06
2039	3.800E+06	5.727E+03	3.129E+06
2040	3.800E+06	5.447E+03	2.976E+06

Carbon dioxide generation predictions for co-disposal wastes using CAA parameters for south area of [redacted] Landfill : waste input period 1973 - 2000

Year	Refuse In Place (Mg)	Carbon Dioxide Emission Rate (Mg/yr)	(Cubic m/yr)
2041	3.800E+06	5.182E+03	2.831E+06
2042	3.800E+06	4.929E+03	2.693E+06
2043	3.800E+06	4.689E+03	2.561E+06
2044	3.800E+06	4.460E+03	2.436E+06
2045	3.800E+06	4.242E+03	2.318E+06
2046	3.800E+06	4.036E+03	2.205E+06
2047	3.800E+06	3.839E+03	2.097E+06
2048	3.800E+06	3.652E+03	1.995E+06
2049	3.800E+06	3.473E+03	1.898E+06
2050	3.800E+06	3.304E+03	1.805E+06
2051	3.800E+06	3.143E+03	1.717E+06
2052	3.800E+06	2.990E+03	1.633E+06
2053	3.800E+06	2.844E+03	1.554E+06
2054	3.800E+06	2.705E+03	1.478E+06
2055	3.800E+06	2.573E+03	1.406E+06
2056	3.800E+06	2.448E+03	1.337E+06
2057	3.800E+06	2.328E+03	1.272E+06
2058	3.800E+06	2.215E+03	1.210E+06
2059	3.800E+06	2.107E+03	1.151E+06
2060	3.800E+06	2.004E+03	1.095E+06
2061	3.800E+06	1.906E+03	1.041E+06
2062	3.800E+06	1.813E+03	9.906E+05
2063	3.800E+06	1.725E+03	9.423E+05
2064	3.800E+06	1.641E+03	8.963E+05
2065	3.800E+06	1.561E+03	8.526E+05
2066	3.800E+06	1.485E+03	8.110E+05
2067	3.800E+06	1.412E+03	7.715E+05
2068	3.800E+06	1.343E+03	7.339E+05
2069	3.800E+06	1.278E+03	6.981E+05
2070	3.800E+06	1.215E+03	6.640E+05
2071	3.800E+06	1.156E+03	6.316E+05
2072	3.800E+06	1.100E+03	6.008E+05
2073	3.800E+06	1.046E+03	5.715E+05
2074	3.800E+06	9.952E+02	5.437E+05
2075	3.800E+06	9.466E+02	5.171E+05
2076	3.800E+06	9.005E+02	4.919E+05
2077	3.800E+06	8.565E+02	4.679E+05
2078	3.800E+06	8.148E+02	4.451E+05
2079	3.800E+06	7.750E+02	4.234E+05
2080	3.800E+06	7.372E+02	4.027E+05
2081	3.800E+06	7.013E+02	3.831E+05

Carbon dioxide generation predictions for co-disposal wastes using CAA parameters for south area of [redacted] Landfill : waste input period 1973 - 2000

Year	Refuse In Place (Mg)	Carbon Dioxide Emission Rate (Mg/yr)	(Cubic m/yr)
2082	3.800E+06	6.671E+02	3.644E+05
2083	3.800E+06	6.345E+02	3.467E+05
2084	3.800E+06	6.036E+02	3.297E+05
2085	3.800E+06	5.742E+02	3.137E+05
2086	3.800E+06	5.462E+02	2.984E+05
2087	3.800E+06	5.195E+02	2.838E+05
2088	3.800E+06	4.942E+02	2.700E+05
2089	3.800E+06	4.701E+02	2.568E+05
2090	3.800E+06	4.472E+02	2.443E+05
2091	3.800E+06	4.253E+02	2.324E+05
2092	3.800E+06	4.046E+02	2.210E+05
2093	3.800E+06	3.849E+02	2.103E+05
2094	3.800E+06	3.661E+02	2.000E+05
2095	3.800E+06	3.482E+02	1.902E+05
2096	3.800E+06	3.313E+02	1.810E+05
2097	3.800E+06	3.151E+02	1.721E+05
2098	3.800E+06	2.997E+02	1.637E+05
2099	3.800E+06	2.851E+02	1.558E+05
2100	3.800E+06	2.712E+02	1.482E+05
2101	3.800E+06	2.580E+02	1.409E+05
2102	3.800E+06	2.454E+02	1.341E+05
2103	3.800E+06	2.334E+02	1.275E+05
2104	3.800E+06	2.221E+02	1.213E+05
2105	3.800E+06	2.112E+02	1.154E+05
2106	3.800E+06	2.009E+02	1.098E+05
2107	3.800E+06	1.911E+02	1.044E+05
2108	3.800E+06	1.818E+02	9.932E+04
2109	3.800E+06	1.729E+02	9.447E+04
2110	3.800E+06	1.645E+02	8.987E+04
2111	3.800E+06	1.565E+02	8.548E+04
2112	3.800E+06	1.488E+02	8.131E+04
2113	3.800E+06	1.416E+02	7.735E+04
2114	3.800E+06	1.347E+02	7.358E+04
2115	3.800E+06	1.281E+02	6.999E+04
2116	3.800E+06	1.219E+02	6.657E+04
2117	3.800E+06	1.159E+02	6.333E+04
2118	3.800E+06	1.103E+02	6.024E+04
2119	3.800E+06	1.049E+02	5.730E+04
2120	3.800E+06	9.977E+01	5.451E+04
2121	3.800E+06	9.491E+01	5.185E+04
2122	3.800E+06	9.028E+01	4.932E+04

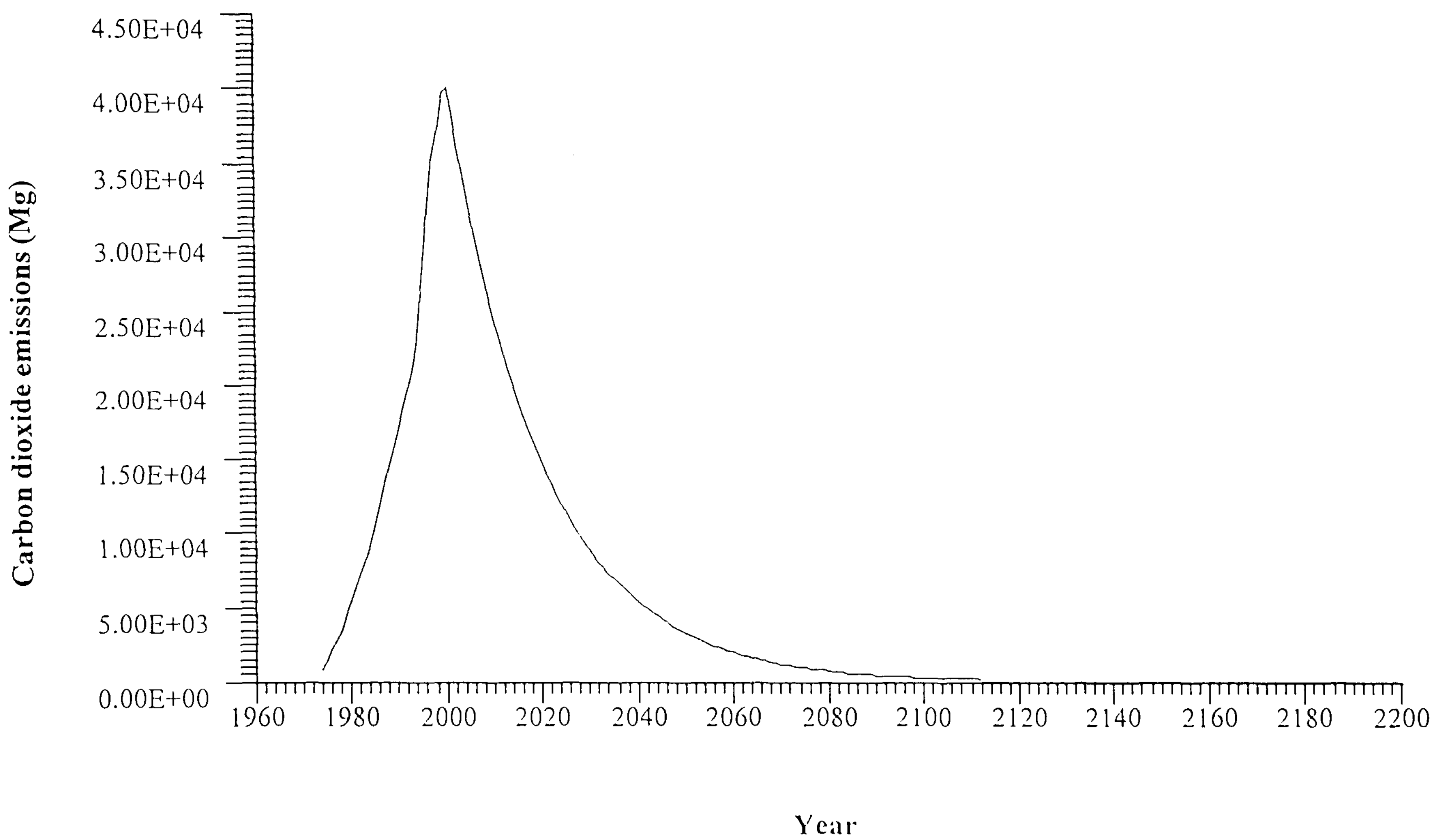
Carbon dioxide generation predictions for co-disposal wastes using CAA parameters for south area of [redacted] Landfill : waste input period 1973 - 2000

Year	Refuse In Place (Mg)	Carbon Dioxide Emission Rate (Mg/yr)	(Cubic m/yr)
2123	3.800E+06	8.588E+01	4.691E+04
2124	3.800E+06	8.169E+01	4.463E+04
2125	3.800E+06	7.770E+01	4.245E+04
2126	3.800E+06	7.391E+01	4.038E+04
2127	3.800E+06	7.031E+01	3.841E+04
2128	3.800E+06	6.688E+01	3.654E+04
2129	3.800E+06	6.362E+01	3.475E+04
2130	3.800E+06	6.052E+01	3.306E+04
2131	3.800E+06	5.756E+01	3.145E+04
2132	3.800E+06	5.476E+01	2.991E+04
2133	3.800E+06	5.209E+01	2.845E+04
2134	3.800E+06	4.955E+01	2.707E+04
2135	3.800E+06	4.713E+01	2.575E+04
2136	3.800E+06	4.483E+01	2.449E+04
2137	3.800E+06	4.264E+01	2.330E+04
2138	3.800E+06	4.056E+01	2.216E+04
2139	3.800E+06	3.859E+01	2.108E+04
2140	3.800E+06	3.670E+01	2.005E+04
2141	3.800E+06	3.491E+01	1.907E+04
2142	3.800E+06	3.321E+01	1.814E+04
2143	3.800E+06	3.159E+01	1.726E+04
2144	3.800E+06	3.005E+01	1.642E+04
2145	3.800E+06	2.859E+01	1.562E+04
2146	3.800E+06	2.719E+01	1.485E+04
2147	3.800E+06	2.587E+01	1.413E+04
2148	3.800E+06	2.460E+01	1.344E+04
2149	3.800E+06	2.340E+01	1.279E+04
2150	3.800E+06	2.226E+01	1.216E+04
2151	3.800E+06	2.118E+01	1.157E+04
2152	3.800E+06	2.014E+01	1.100E+04
2153	3.800E+06	1.916E+01	1.047E+04
2154	3.800E+06	1.823E+01	9.957E+03
2155	3.800E+06	1.734E+01	9.472E+03
2156	3.800E+06	1.649E+01	9.010E+03
2157	3.800E+06	1.569E+01	8.570E+03
2158	3.800E+06	1.492E+01	8.152E+03
2159	3.800E+06	1.420E+01	7.755E+03
2160	3.800E+06	1.350E+01	7.377E+03
2161	3.800E+06	1.284E+01	7.017E+03
2162	3.800E+06	1.222E+01	6.675E+03
2163	3.800E+06	1.162E+01	6.349E+03

Carbon dioxide generation predictions for co-disposal wastes using CAA parameters for south area of [redacted] Landfill : waste input period 1973 - 2000

Year	Refuse In Place (Mg)	Carbon Dioxide Emission Rate (Mg/yr)	Carbon Dioxide Emission Rate (Cubic m/yr)
2164	3.800E+06	1.106E+01	6.039E+03
2165	3.800E+06	1.052E+01	5.745E+03
2166	3.800E+06	1.000E+01	5.465E+03
2167	3.800E+06	9.515E+00	5.198E+03
2168	3.800E+06	9.051E+00	4.945E+03
2169	3.800E+06	8.610E+00	4.704E+03
2170	3.800E+06	8.190E+00	4.474E+03
2171	3.800E+06	7.790E+00	4.256E+03
2172	3.800E+06	7.411E+00	4.048E+03
2173	3.800E+06	7.049E+00	3.851E+03
2174	3.800E+06	6.705E+00	3.663E+03
2175	3.800E+06	6.378E+00	3.484E+03
2176	3.800E+06	6.067E+00	3.315E+03
2177	3.800E+06	5.771E+00	3.153E+03
2178	3.800E+06	5.490E+00	2.999E+03
2179	3.800E+06	5.222E+00	2.853E+03
2180	3.800E+06	4.967E+00	2.714E+03
2181	3.800E+06	4.725E+00	2.581E+03
2182	3.800E+06	4.495E+00	2.455E+03
2183	3.800E+06	4.276E+00	2.336E+03
2184	3.800E+06	4.067E+00	2.222E+03
2185	3.800E+06	3.869E+00	2.113E+03
2186	3.800E+06	3.680E+00	2.010E+03
2187	3.800E+06	3.500E+00	1.912E+03
2188	3.800E+06	3.330E+00	1.819E+03
2189	3.800E+06	3.167E+00	1.730E+03
2190	3.800E+06	3.013E+00	1.646E+03
2191	3.800E+06	2.866E+00	1.566E+03
2192	3.800E+06	2.726E+00	1.489E+03
2193	3.800E+06	2.593E+00	1.417E+03
2194	3.800E+06	2.467E+00	1.348E+03
2195	3.800E+06	2.346E+00	1.282E+03
2196	3.800E+06	2.232E+00	1.219E+03
2197	3.800E+06	2.123E+00	1.160E+03
2198	3.800E+06	2.020E+00	1.103E+03
2199	3.800E+06	1.921E+00	1.050E+03

Projected Carbon Dioxide Emissions for co-disposal using CAA parameters for south area of landfill



APPENDIX D

Model 2 - [redacted] East (Domestic - no adjustment for inerts)

Methane generation predictions for domestic wastes using CAA parameters for eastern extension area of [redacted] : waste input period 1999 - 2010

Model Parameters

Lo : 170.00 m^3 / Mg
k : 0.0500 1/yr
NMOC : 4000.00 ppmv
Methane : 50.0000 % volume
Carbon Dioxide : 50.0000 % volume

Landfill Parameters

Landfill type : No Co-Disposal
Year Opened : 1999 Current Year : 2010 Closure Year: 2010
Capacity : 2900000 Mg
Average Acceptance Rate Required from
Current Year to Closure Year : 0.00 Mg/year

Model Results

		Methane Emission Rate	
Year	Refuse In Place (Mg)	(Mg/yr)	(Cubic m/yr)
2000	1.300E+05	7.372E+02	1.105E+06
2001	4.300E+05	2.402E+03	3.601E+06
2002	7.300E+05	3.987E+03	5.975E+06
2003	1.030E+06	5.493E+03	8.234E+06
2004	1.330E+06	6.927E+03	1.038E+07
2005	1.630E+06	8.290E+03	1.243E+07
2006	1.930E+06	9.587E+03	1.437E+07
2007	2.230E+06	1.082E+04	1.622E+07
2008	2.530E+06	1.199E+04	1.798E+07
2009	2.810E+06	1.300E+04	1.948E+07
2010	2.900E+06	1.287E+04	1.930E+07
2011	2.900E+06	1.225E+04	1.836E+07
2012	2.900E+06	1.165E+04	1.746E+07
2013	2.900E+06	1.108E+04	1.661E+07
2014	2.900E+06	1.054E+04	1.580E+07
2015	2.900E+06	1.003E+04	1.503E+07
2016	2.900E+06	9.537E+03	1.430E+07
2017	2.900E+06	9.072E+03	1.360E+07
2018	2.900E+06	8.629E+03	1.293E+07
2019	2.900E+06	8.209E+03	1.230E+07
2020	2.900E+06	7.808E+03	1.170E+07
2021	2.900E+06	7.427E+03	1.113E+07
2022	2.900E+06	7.065E+03	1.059E+07
2023	2.900E+06	6.721E+03	1.007E+07
2024	2.900E+06	6.393E+03	9.582E+06
2025	2.900E+06	6.081E+03	9.115E+06

Methane generation predictions for domestic wastes using CAA parameters for eastern extension area of [redacted] : waste input period 1999 - 2010

Year	Refuse In Place (Mg)	Methane Emission Rate (Mg/yr)	(Cubic m/yr)
2026	2.900E+06	5.784E+03	8.670E+06
2027	2.900E+06	5.502E+03	8.248E+06
2028	2.900E+06	5.234E+03	7.845E+06
2029	2.900E+06	4.979E+03	7.463E+06
2030	2.900E+06	4.736E+03	7.099E+06
2031	2.900E+06	4.505E+03	6.753E+06
2032	2.900E+06	4.285E+03	6.423E+06
2033	2.900E+06	4.076E+03	6.110E+06
2034	2.900E+06	3.877E+03	5.812E+06
2035	2.900E+06	3.688E+03	5.528E+06
2036	2.900E+06	3.508E+03	5.259E+06
2037	2.900E+06	3.337E+03	5.002E+06
2038	2.900E+06	3.175E+03	4.758E+06
2039	2.900E+06	3.020E+03	4.526E+06
2040	2.900E+06	2.872E+03	4.306E+06
2041	2.900E+06	2.732E+03	4.096E+06
2042	2.900E+06	2.599E+03	3.896E+06
2043	2.900E+06	2.472E+03	3.706E+06
2044	2.900E+06	2.352E+03	3.525E+06
2045	2.900E+06	2.237E+03	3.353E+06
2046	2.900E+06	2.128E+03	3.190E+06
2047	2.900E+06	2.024E+03	3.034E+06
2048	2.900E+06	1.925E+03	2.886E+06
2049	2.900E+06	1.832E+03	2.745E+06
2050	2.900E+06	1.742E+03	2.611E+06
2051	2.900E+06	1.657E+03	2.484E+06
2052	2.900E+06	1.576E+03	2.363E+06
2053	2.900E+06	1.500E+03	2.248E+06
2054	2.900E+06	1.426E+03	2.138E+06
2055	2.900E+06	1.357E+03	2.034E+06
2056	2.900E+06	1.291E+03	1.935E+06
2057	2.900E+06	1.228E+03	1.840E+06
2058	2.900E+06	1.168E+03	1.751E+06
2059	2.900E+06	1.111E+03	1.665E+06
2060	2.900E+06	1.057E+03	1.584E+06
2061	2.900E+06	1.005E+03	1.507E+06
2062	2.900E+06	9.562E+02	1.433E+06
2063	2.900E+06	9.095E+02	1.363E+06
2064	2.900E+06	8.652E+02	1.297E+06
2065	2.900E+06	8.230E+02	1.234E+06
2066	2.900E+06	7.828E+02	1.173E+06

Methane generation predictions for domestic wastes using CAA parameters for eastern extension area of [redacted] : waste input period 1999 - 2010

Year	Refuse In Place (Mg)	Methane Emission Rate (Mg/yr)	(Cubic m/yr)
2067	2.900E+06	7.447E+02	1.116E+06
2068	2.900E+06	7.083E+02	1.062E+06
2069	2.900E+06	6.738E+02	1.010E+06
2070	2.900E+06	6.409E+02	9.607E+05
2071	2.900E+06	6.097E+02	9.139E+05
2072	2.900E+06	5.799E+02	8.693E+05
2073	2.900E+06	5.517E+02	8.269E+05
2074	2.900E+06	5.248E+02	7.866E+05
2075	2.900E+06	4.992E+02	7.482E+05
2076	2.900E+06	4.748E+02	7.117E+05
2077	2.900E+06	4.517E+02	6.770E+05
2078	2.900E+06	4.296E+02	6.440E+05
2079	2.900E+06	4.087E+02	6.126E+05
2080	2.900E+06	3.887E+02	5.827E+05
2081	2.900E+06	3.698E+02	5.543E+05
2082	2.900E+06	3.518E+02	5.272E+05
2083	2.900E+06	3.346E+02	5.015E+05
2084	2.900E+06	3.183E+02	4.771E+05
2085	2.900E+06	3.028E+02	4.538E+05
2086	2.900E+06	2.880E+02	4.317E+05
2087	2.900E+06	2.739E+02	4.106E+05
2088	2.900E+06	2.606E+02	3.906E+05
2089	2.900E+06	2.479E+02	3.715E+05
2090	2.900E+06	2.358E+02	3.534E+05
2091	2.900E+06	2.243E+02	3.362E+05
2092	2.900E+06	2.133E+02	3.198E+05
2093	2.900E+06	2.029E+02	3.042E+05
2094	2.900E+06	1.930E+02	2.894E+05
2095	2.900E+06	1.836E+02	2.752E+05
2096	2.900E+06	1.747E+02	2.618E+05
2097	2.900E+06	1.662E+02	2.491E+05
2098	2.900E+06	1.581E+02	2.369E+05
2099	2.900E+06	1.503E+02	2.254E+05
2100	2.900E+06	1.430E+02	2.144E+05
2101	2.900E+06	1.360E+02	2.039E+05
2102	2.900E+06	1.294E+02	1.940E+05
2103	2.900E+06	1.231E+02	1.845E+05
2104	2.900E+06	1.171E+02	1.755E+05
2105	2.900E+06	1.114E+02	1.669E+05
2106	2.900E+06	1.059E+02	1.588E+05
2107	2.900E+06	1.008E+02	1.511E+05

Methane generation predictions for domestic wastes using CAA parameters for eastern extension area of [redacted]: waste input period 1999 - 2010

Year	Refuse In Place (Mg)	Methane Emission Rate (Mg/yr)	(Cubic m/yr)
2108	2.900E+06	9.586E+01	1.437E+05
2109	2.900E+06	9.119E+01	1.367E+05
2110	2.900E+06	8.674E+01	1.300E+05
2111	2.900E+06	8.251E+01	1.237E+05
2112	2.900E+06	7.849E+01	1.176E+05
2113	2.900E+06	7.466E+01	1.119E+05
2114	2.900E+06	7.102E+01	1.064E+05
2115	2.900E+06	6.755E+01	1.013E+05
2116	2.900E+06	6.426E+01	9.632E+04
2117	2.900E+06	6.113E+01	9.162E+04
2118	2.900E+06	5.814E+01	8.715E+04
2119	2.900E+06	5.531E+01	8.290E+04
2120	2.900E+06	5.261E+01	7.886E+04
2121	2.900E+06	5.005E+01	7.501E+04
2122	2.900E+06	4.760E+01	7.136E+04
2123	2.900E+06	4.528E+01	6.788E+04
2124	2.900E+06	4.307E+01	6.456E+04
2125	2.900E+06	4.097E+01	6.142E+04
2126	2.900E+06	3.898E+01	5.842E+04
2127	2.900E+06	3.707E+01	5.557E+04
2128	2.900E+06	3.527E+01	5.286E+04
2129	2.900E+06	3.355E+01	5.028E+04
2130	2.900E+06	3.191E+01	4.783E+04
2131	2.900E+06	3.035E+01	4.550E+04
2132	2.900E+06	2.887E+01	4.328E+04
2133	2.900E+06	2.747E+01	4.117E+04
2134	2.900E+06	2.613E+01	3.916E+04
2135	2.900E+06	2.485E+01	3.725E+04
2136	2.900E+06	2.364E+01	3.543E+04
2137	2.900E+06	2.249E+01	3.371E+04
2138	2.900E+06	2.139E+01	3.206E+04
2139	2.900E+06	2.035E+01	3.050E+04
2140	2.900E+06	1.935E+01	2.901E+04
2141	2.900E+06	1.841E+01	2.760E+04
2142	2.900E+06	1.751E+01	2.625E+04
2143	2.900E+06	1.666E+01	2.497E+04
2144	2.900E+06	1.585E+01	2.375E+04
2145	2.900E+06	1.507E+01	2.259E+04
2146	2.900E+06	1.434E+01	2.149E+04
2147	2.900E+06	1.364E+01	2.044E+04
2148	2.900E+06	1.297E+01	1.945E+04

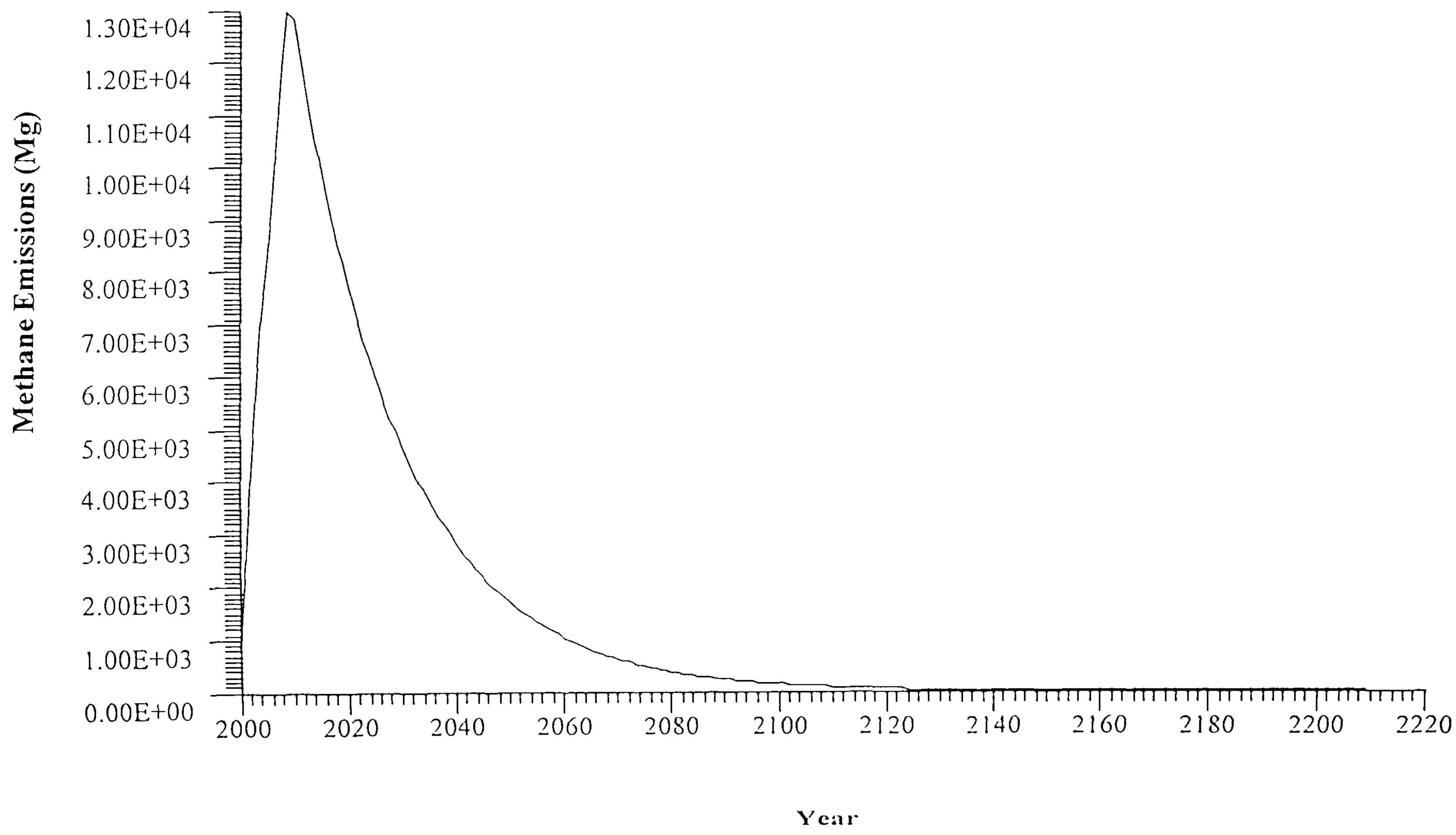
Methane generation predictions for domestic wastes using CAA parameters for eastern extension area of [redacted] : waste input period 1999 - 2010

Year	Refuse In Place (Mg)	Methane Emission Rate (Mg/yr)	(Cubic m/yr)
2149	2.900E+06	1.234E+01	1.850E+04
2150	2.900E+06	1.174E+01	1.760E+04
2151	2.900E+06	1.117E+01	1.674E+04
2152	2.900E+06	1.062E+01	1.592E+04
2153	2.900E+06	1.010E+01	1.514E+04
2154	2.900E+06	9.611E+00	1.441E+04
2155	2.900E+06	9.142E+00	1.370E+04
2156	2.900E+06	8.697E+00	1.304E+04
2157	2.900E+06	8.272E+00	1.240E+04
2158	2.900E+06	7.869E+00	1.179E+04
2159	2.900E+06	7.485E+00	1.122E+04
2160	2.900E+06	7.120E+00	1.067E+04
2161	2.900E+06	6.773E+00	1.015E+04
2162	2.900E+06	6.443E+00	9.657E+03
2163	2.900E+06	6.128E+00	9.186E+03
2164	2.900E+06	5.829E+00	8.738E+03
2165	2.900E+06	5.545E+00	8.312E+03
2166	2.900E+06	5.275E+00	7.906E+03
2167	2.900E+06	5.017E+00	7.521E+03
2168	2.900E+06	4.773E+00	7.154E+03
2169	2.900E+06	4.540E+00	6.805E+03
2170	2.900E+06	4.319E+00	6.473E+03
2171	2.900E+06	4.108E+00	6.157E+03
2172	2.900E+06	3.908E+00	5.857E+03
2173	2.900E+06	3.717E+00	5.572E+03
2174	2.900E+06	3.536E+00	5.300E+03
2175	2.900E+06	3.363E+00	5.041E+03
2176	2.900E+06	3.199E+00	4.795E+03
2177	2.900E+06	3.043E+00	4.562E+03
2178	2.900E+06	2.895E+00	4.339E+03
2179	2.900E+06	2.754E+00	4.127E+03
2180	2.900E+06	2.619E+00	3.926E+03
2181	2.900E+06	2.492E+00	3.735E+03
2182	2.900E+06	2.370E+00	3.553E+03
2183	2.900E+06	2.254E+00	3.379E+03
2184	2.900E+06	2.145E+00	3.214E+03
2185	2.900E+06	2.040E+00	3.058E+03
2186	2.900E+06	1.940E+00	2.909E+03
2187	2.900E+06	1.846E+00	2.767E+03
2188	2.900E+06	1.756E+00	2.632E+03
2189	2.900E+06	1.670E+00	2.503E+03

Methane generation predictions for domestic wastes using CAA parameters for eastern extension area of [redacted] : waste input period 1999 - 2010

		Methane Emission Rate	
Year	Refuse In Place (Mg)	(Mg/yr)	(Cubic m/yr)
2190	2.900E+06	1.589E+00	2.381E+03
2191	2.900E+06	1.511E+00	2.265E+03
2192	2.900E+06	1.438E+00	2.155E+03
2193	2.900E+06	1.367E+00	2.050E+03
2194	2.900E+06	1.301E+00	1.950E+03
2195	2.900E+06	1.237E+00	1.855E+03
2196	2.900E+06	1.177E+00	1.764E+03
2197	2.900E+06	1.120E+00	1.678E+03
2198	2.900E+06	1.065E+00	1.596E+03
2199	2.900E+06	1.013E+00	1.518E+03
2200	2.900E+06	9.636E-01	1.444E+03
2201	2.900E+06	9.166E-01	1.374E+03
2202	2.900E+06	8.719E-01	1.307E+03
2203	2.900E+06	8.294E-01	1.243E+03
2204	2.900E+06	7.889E-01	1.183E+03
2205	2.900E+06	7.505E-01	1.125E+03
2206	2.900E+06	7.139E-01	1.070E+03
2207	2.900E+06	6.790E-01	1.018E+03
2208	2.900E+06	6.459E-01	9.682E+02
2209	2.900E+06	6.144E-01	9.210E+02

Projected Methane emissions for domestic waste using
CAA parameters for eastern extension area of landfill



Carbon dioxide generation predictions for domestic wastes using CAA parameters for eastern extension area of [redacted] Landfill : waste input period 1973 -2010

Model Parameters

Lo : 170.00 m^3 / Mg
k : 0.0500 1/yr
NMOC : 4000.00 ppmv
Methane : 50.0000 % volume
Carbon Dioxide : 50.0000 % volume

Landfill Parameters

Landfill type : No Co-Disposal
Year Opened : 1999 Current Year : 2010 Closure Year: 2010
Capacity : 2900000 Mg
Average Acceptance Rate Required from
Current Year to Closure Year : 0.00 Mg/year

Model Results

		Carbon Dioxide Emission Rate	
Year	Rcfuse In Place (Mg)	(Mg/yr)	(Cubic m/yr)
2000	1.300E+05	2.023E+03	1.105E+06
2001	4.300E+05	6.592E+03	3.601E+06
2002	7.300E+05	1.094E+04	5.975E+06
2003	1.030E+06	1.507E+04	8.234E+06
2004	1.330E+06	1.901E+04	1.038E+07
2005	1.630E+06	2.275E+04	1.243E+07
2006	1.930E+06	2.630E+04	1.437E+07
2007	2.230E+06	2.969E+04	1.622E+07
2008	2.530E+06	3.291E+04	1.798E+07
2009	2.810E+06	3.566E+04	1.948E+07
2010	2.900E+06	3.532E+04	1.930E+07
2011	2.900E+06	3.360E+04	1.836E+07
2012	2.900E+06	3.196E+04	1.746E+07
2013	2.900E+06	3.040E+04	1.661E+07
2014	2.900E+06	2.892E+04	1.580E+07
2015	2.900E+06	2.751E+04	1.503E+07
2016	2.900E+06	2.617E+04	1.430E+07
2017	2.900E+06	2.489E+04	1.360E+07
2018	2.900E+06	2.368E+04	1.293E+07
2019	2.900E+06	2.252E+04	1.230E+07
2020	2.900E+06	2.142E+04	1.170E+07
2021	2.900E+06	2.038E+04	1.113E+07
2022	2.900E+06	1.939E+04	1.059E+07
2023	2.900E+06	1.844E+04	1.007E+07
2024	2.900E+06	1.754E+04	9.582E+06
2025	2.900E+06	1.668E+04	9.115E+06

Carbon dioxide generation predictions for domestic wastes using CAA parameters for eastern extension area of [redacted] Landfill : waste input period 1973 -2010

Year	Refuse In Place (Mg)	Carbon Dioxide Emission Rate (Mg/yr)	(Cubic m/yr)
2026	2.900E+06	1.587E+04	8.670E+06
2027	2.900E+06	1.510E+04	8.248E+06
2028	2.900E+06	1.436E+04	7.845E+06
2029	2.900E+06	1.366E+04	7.463E+06
2030	2.900E+06	1.299E+04	7.099E+06
2031	2.900E+06	1.236E+04	6.753E+06
2032	2.900E+06	1.176E+04	6.423E+06
2033	2.900E+06	1.118E+04	6.110E+06
2034	2.900E+06	1.064E+04	5.812E+06
2035	2.900E+06	1.012E+04	5.528E+06
2036	2.900E+06	9.626E+03	5.259E+06
2037	2.900E+06	9.157E+03	5.002E+06
2038	2.900E+06	8.710E+03	4.758E+06
2039	2.900E+06	8.285E+03	4.526E+06
2040	2.900E+06	7.881E+03	4.306E+06
2041	2.900E+06	7.497E+03	4.096E+06
2042	2.900E+06	7.131E+03	3.896E+06
2043	2.900E+06	6.784E+03	3.706E+06
2044	2.900E+06	6.453E+03	3.525E+06
2045	2.900E+06	6.138E+03	3.353E+06
2046	2.900E+06	5.839E+03	3.190E+06
2047	2.900E+06	5.554E+03	3.034E+06
2048	2.900E+06	5.283E+03	2.886E+06
2049	2.900E+06	5.025E+03	2.745E+06
2050	2.900E+06	4.780E+03	2.611E+06
2051	2.900E+06	4.547E+03	2.484E+06
2052	2.900E+06	4.325E+03	2.363E+06
2053	2.900E+06	4.114E+03	2.248E+06
2054	2.900E+06	3.914E+03	2.138E+06
2055	2.900E+06	3.723E+03	2.034E+06
2056	2.900E+06	3.541E+03	1.935E+06
2057	2.900E+06	3.369E+03	1.840E+06
2058	2.900E+06	3.204E+03	1.751E+06
2059	2.900E+06	3.048E+03	1.665E+06
2060	2.900E+06	2.899E+03	1.584E+06
2061	2.900E+06	2.758E+03	1.507E+06
2062	2.900E+06	2.623E+03	1.433E+06
2063	2.900E+06	2.496E+03	1.363E+06
2064	2.900E+06	2.374E+03	1.297E+06
2065	2.900E+06	2.258E+03	1.234E+06
2066	2.900E+06	2.148E+03	1.173E+06

Carbon dioxide generation predictions for domestic wastes using CAA parameters for eastern extension area of [redacted] Landfill : waste input period 1973 -2010

		Carbon Dioxide Emission Rate	
Year	Refuse In Place (Mg)	(Mg/yr)	(Cubic m/yr)
2067	2.900E+06	2.043E+03	1.116E+06
2068	2.900E+06	1.944E+03	1.062E+06
2069	2.900E+06	1.849E+03	1.010E+06
2070	2.900E+06	1.759E+03	9.607E+05
2071	2.900E+06	1.673E+03	9.139E+05
2072	2.900E+06	1.591E+03	8.693E+05
2073	2.900E+06	1.514E+03	8.269E+05
2074	2.900E+06	1.440E+03	7.866E+05
2075	2.900E+06	1.370E+03	7.482E+05
2076	2.900E+06	1.303E+03	7.117E+05
2077	2.900E+06	1.239E+03	6.770E+05
2078	2.900E+06	1.179E+03	6.440E+05
2079	2.900E+06	1.121E+03	6.126E+05
2080	2.900E+06	1.067E+03	5.827E+05
2081	2.900E+06	1.015E+03	5.543E+05
2082	2.900E+06	9.651E+02	5.272E+05
2083	2.900E+06	9.181E+02	5.015E+05
2084	2.900E+06	8.733E+02	4.771E+05
2085	2.900E+06	8.307E+02	4.538E+05
2086	2.900E+06	7.902E+02	4.317E+05
2087	2.900E+06	7.516E+02	4.106E+05
2088	2.900E+06	7.150E+02	3.906E+05
2089	2.900E+06	6.801E+02	3.715E+05
2090	2.900E+06	6.469E+02	3.534E+05
2091	2.900E+06	6.154E+02	3.362E+05
2092	2.900E+06	5.854E+02	3.198E+05
2093	2.900E+06	5.568E+02	3.042E+05
2094	2.900E+06	5.297E+02	2.894E+05
2095	2.900E+06	5.038E+02	2.752E+05
2096	2.900E+06	4.793E+02	2.618E+05
2097	2.900E+06	4.559E+02	2.491E+05
2098	2.900E+06	4.337E+02	2.369E+05
2099	2.900E+06	4.125E+02	2.254E+05
2100	2.900E+06	3.924E+02	2.144E+05
2101	2.900E+06	3.733E+02	2.039E+05
2102	2.900E+06	3.550E+02	1.940E+05
2103	2.900E+06	3.377E+02	1.845E+05
2104	2.900E+06	3.213E+02	1.755E+05
2105	2.900E+06	3.056E+02	1.669E+05
2106	2.900E+06	2.907E+02	1.588E+05
2107	2.900E+06	2.765E+02	1.511E+05

Carbon dioxide generation predictions for domestic wastes using CAA parameters for eastern extension area of [redacted] Landfill : waste input period 1973 -2010

Year	Refuse In Place (Mg)	Carbon Dioxide Emission Rate (Mg/yr)	(Cubic m/yr)
2108	2.900E+06	2.630E+02	1.437E+05
2109	2.900E+06	2.502E+02	1.367E+05
2110	2.900E+06	2.380E+02	1.300E+05
2111	2.900E+06	2.264E+02	1.237E+05
2112	2.900E+06	2.153E+02	1.176E+05
2113	2.900E+06	2.048E+02	1.119E+05
2114	2.900E+06	1.949E+02	1.064E+05
2115	2.900E+06	1.854E+02	1.013E+05
2116	2.900E+06	1.763E+02	9.632E+04
2117	2.900E+06	1.677E+02	9.162E+04
2118	2.900E+06	1.595E+02	8.715E+04
2119	2.900E+06	1.518E+02	8.290E+04
2120	2.900E+06	1.444E+02	7.886E+04
2121	2.900E+06	1.373E+02	7.501E+04
2122	2.900E+06	1.306E+02	7.136E+04
2123	2.900E+06	1.242E+02	6.788E+04
2124	2.900E+06	1.182E+02	6.456E+04
2125	2.900E+06	1.124E+02	6.142E+04
2126	2.900E+06	1.069E+02	5.842E+04
2127	2.900E+06	1.017E+02	5.557E+04
2128	2.900E+06	9.676E+01	5.286E+04
2129	2.900E+06	9.204E+01	5.028E+04
2130	2.900E+06	8.755E+01	4.783E+04
2131	2.900E+06	8.328E+01	4.550E+04
2132	2.900E+06	7.922E+01	4.328E+04
2133	2.900E+06	7.536E+01	4.117E+04
2134	2.900E+06	7.168E+01	3.916E+04
2135	2.900E+06	6.819E+01	3.725E+04
2136	2.900E+06	6.486E+01	3.543E+04
2137	2.900E+06	6.170E+01	3.371E+04
2138	2.900E+06	5.869E+01	3.206E+04
2139	2.900E+06	5.583E+01	3.050E+04
2140	2.900E+06	5.310E+01	2.901E+04
2141	2.900E+06	5.051E+01	2.760E+04
2142	2.900E+06	4.805E+01	2.625E+04
2143	2.900E+06	4.571E+01	2.497E+04
2144	2.900E+06	4.348E+01	2.375E+04
2145	2.900E+06	4.136E+01	2.259E+04
2146	2.900E+06	3.934E+01	2.149E+04
2147	2.900E+06	3.742E+01	2.044E+04
2148	2.900E+06	3.560E+01	1.945E+04

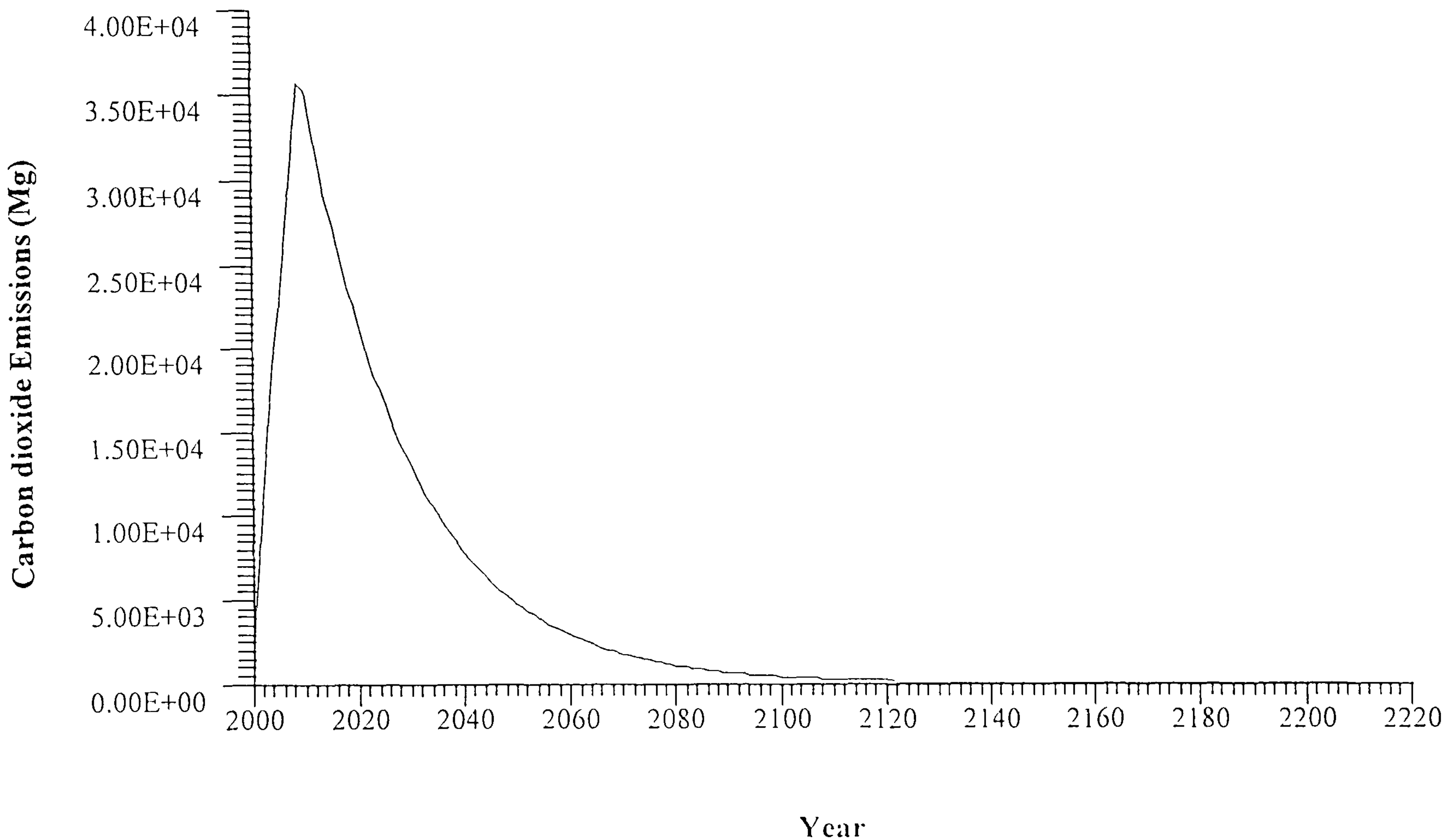
Carbon dioxide generation predictions for domestic wastes using CAA parameters for eastern extension area of [redacted] Landfill : waste input period 1973 -2010

		Carbon Dioxide Emission Rate	
Year	Refuse In Place (Mg)	(Mg/yr)	(Cubic m/yr)
2149	2.900E+06	3.386E+01	1.850E+04
2150	2.900E+06	3.221E+01	1.760E+04
2151	2.900E+06	3.064E+01	1.674E+04
2152	2.900E+06	2.914E+01	1.592E+04
2153	2.900E+06	2.772E+01	1.514E+04
2154	2.900E+06	2.637E+01	1.441E+04
2155	2.900E+06	2.508E+01	1.370E+04
2156	2.900E+06	2.386E+01	1.304E+04
2157	2.900E+06	2.270E+01	1.240E+04
2158	2.900E+06	2.159E+01	1.179E+04
2159	2.900E+06	2.054E+01	1.122E+04
2160	2.900E+06	1.954E+01	1.067E+04
2161	2.900E+06	1.858E+01	1.015E+04
2162	2.900E+06	1.768E+01	9.657E+03
2163	2.900E+06	1.681E+01	9.186E+03
2164	2.900E+06	1.599E+01	8.738E+03
2165	2.900E+06	1.521E+01	8.312E+03
2166	2.900E+06	1.447E+01	7.906E+03
2167	2.900E+06	1.377E+01	7.521E+03
2168	2.900E+06	1.310E+01	7.154E+03
2169	2.900E+06	1.246E+01	6.805E+03
2170	2.900E+06	1.185E+01	6.473E+03
2171	2.900E+06	1.127E+01	6.157E+03
2172	2.900E+06	1.072E+01	5.857E+03
2173	2.900E+06	1.020E+01	5.572E+03
2174	2.900E+06	9.701E+00	5.300E+03
2175	2.900E+06	9.228E+00	5.041E+03
2176	2.900E+06	8.778E+00	4.795E+03
2177	2.900E+06	8.350E+00	4.562E+03
2178	2.900E+06	7.943E+00	4.339E+03
2179	2.900E+06	7.555E+00	4.127E+03
2180	2.900E+06	7.187E+00	3.926E+03
2181	2.900E+06	6.836E+00	3.735E+03
2182	2.900E+06	6.503E+00	3.553E+03
2183	2.900E+06	6.186E+00	3.379E+03
2184	2.900E+06	5.884E+00	3.214E+03
2185	2.900E+06	5.597E+00	3.058E+03
2186	2.900E+06	5.324E+00	2.909E+03
2187	2.900E+06	5.065E+00	2.767E+03
2188	2.900E+06	4.818E+00	2.632E+03
2189	2.900E+06	4.583E+00	2.503E+03

Carbon dioxide generation predictions for domestic wastes using CAA parameters for eastern extension area of [redacted] Landfill : waste input period 1973 -2010

Year	Refuse In Place (Mg)	Carbon Dioxide Emission Rate (Mg/yr)	Carbon Dioxide Emission Rate (Cubic m/yr)
2190	2.900E+06	4.359E+00	2.381E+03
2191	2.900E+06	4.146E+00	2.265E+03
2192	2.900E+06	3.944E+00	2.155E+03
2193	2.900E+06	3.752E+00	2.050E+03
2194	2.900E+06	3.569E+00	1.950E+03
2195	2.900E+06	3.395E+00	1.855E+03
2196	2.900E+06	3.229E+00	1.764E+03
2197	2.900E+06	3.072E+00	1.678E+03
2198	2.900E+06	2.922E+00	1.596E+03
2199	2.900E+06	2.779E+00	1.518E+03
2200	2.900E+06	2.644E+00	1.444E+03
2201	2.900E+06	2.515E+00	1.374E+03
2202	2.900E+06	2.392E+00	1.307E+03
2203	2.900E+06	2.276E+00	1.243E+03
2204	2.900E+06	2.165E+00	1.183E+03
2205	2.900E+06	2.059E+00	1.125E+03
2206	2.900E+06	1.959E+00	1.070E+03
2207	2.900E+06	1.863E+00	1.018E+03
2208	2.900E+06	1.772E+00	9.682E+02
2209	2.900E+06	1.686E+00	9.210E+02

Projected Carbon Dioxide Emissions for domestic waste using CAA parameters for eastern extension area of landfill



APPENDIX E

Model 3 - [redacted] Total Waste Volume (Domestic - no adjustment for inerts)

Methane generation predictions for domestic wastes using CAA parameters for total area of [redacted] Landfill : waste input period 1973 - 2010

Model Parameters

Lo : 170.00 m^3 / Mg
k : 0.0500 1/yr
NMOC : 4000.00 ppmv
Methane : 50.0000 % volume
Carbon Dioxide : 50.0000 % volume

Landfill Parameters

Landfill type : No Co-Disposal
Year Opened : 1973   Current Year : 2010 Closure Year: 2010
Capacity : 6700000 Mg
Average Acceptance Rate Required from
Current Year to Closure Year : 0.00 Mg/year

Model Results

		Methane Emission Rate	
Year	Refuse In Place (Mg)	(Mg/yr)	(Cubic m/yr)
1974	5.000E+04	2.835E+02	4.250E+05
1975	1.000E+05	5.532E+02	8.293E+05
1976	1.500E+05	8.098E+02	1.214E+06
1977	2.000E+05	1.054E+03	1.580E+06
1978	2.500E+05	1.286E+03	1.928E+06
1979	3.250E+05	1.649E+03	2.471E+06
1980	4.000E+05	1.993E+03	2.988E+06
1981	4.750E+05	2.322E+03	3.480E+06
1982	5.500E+05	2.634E+03	3.948E+06
1983	6.250E+05	2.931E+03	4.393E+06
1984	7.250E+05	3.355E+03	5.028E+06
1985	8.250E+05	3.758E+03	5.633E+06
1986	9.500E+05	4.284E+03	6.421E+06
1987	1.075E+06	4.784E+03	7.170E+06
1988	1.200E+06	5.259E+03	7.883E+06
1989	1.325E+06	5.712E+03	8.561E+06
1990	1.450E+06	6.142E+03	9.206E+06
1991	1.600E+06	6.693E+03	1.003E+07
1992	1.750E+06	7.217E+03	1.082E+07
1993	1.900E+06	7.716E+03	1.157E+07
1994	2.070E+06	8.303E+03	1.245E+07
1995	2.420E+06	9.883E+03	1.481E+07
1996	2.770E+06	1.139E+04	1.707E+07
1997	3.120E+06	1.282E+04	1.921E+07
1998	3.385E+06	1.369E+04	2.052E+07
1999	3.650E+06	1.453E+04	2.178E+07

Methane generation predictions for domestic wastes using CAA parameters for total area of [redacted] Landfill : waste input period 1973 - 2010

		Methane Emission Rate	
Year	Refuse In Place (Mg)	(Mg/yr)	(Cubic m/yr)
2000	3.915E+06	1.532E+04	2.297E+07
2001	4.195E+06	1.616E+04	2.423E+07
2002	4.475E+06	1.696E+04	2.543E+07
2003	4.755E+06	1.772E+04	2.657E+07
2004	5.035E+06	1.845E+04	2.765E+07
2005	5.315E+06	1.913E+04	2.868E+07
2006	5.595E+06	1.979E+04	2.966E+07
2007	5.875E+06	2.041E+04	3.060E+07
2008	6.155E+06	2.100E+04	3.148E+07
2009	6.435E+06	2.157E+04	3.233E+07
2010	6.700E+06	2.202E+04	3.300E+07
2011	6.700E+06	2.094E+04	3.139E+07
2012	6.700E+06	1.992E+04	2.986E+07
2013	6.700E+06	1.895E+04	2.841E+07
2014	6.700E+06	1.803E+04	2.702E+07
2015	6.700E+06	1.715E+04	2.570E+07
2016	6.700E+06	1.631E+04	2.445E+07
2017	6.700E+06	1.552E+04	2.326E+07
2018	6.700E+06	1.476E+04	2.212E+07
2019	6.700E+06	1.404E+04	2.104E+07
2020	6.700E+06	1.335E+04	2.002E+07
2021	6.700E+06	1.270E+04	1.904E+07
2022	6.700E+06	1.208E+04	1.811E+07
2023	6.700E+06	1.149E+04	1.723E+07
2024	6.700E+06	1.093E+04	1.639E+07
2025	6.700E+06	1.040E+04	1.559E+07
2026	6.700E+06	9.894E+03	1.483E+07
2027	6.700E+06	9.411E+03	1.411E+07
2028	6.700E+06	8.952E+03	1.342E+07
2029	6.700E+06	8.515E+03	1.276E+07
2030	6.700E+06	8.100E+03	1.214E+07
2031	6.700E+06	7.705E+03	1.155E+07
2032	6.700E+06	7.329E+03	1.099E+07
2033	6.700E+06	6.972E+03	1.045E+07
2034	6.700E+06	6.632E+03	9.941E+06
2035	6.700E+06	6.308E+03	9.456E+06
2036	6.700E+06	6.001E+03	8.995E+06
2037	6.700E+06	5.708E+03	8.556E+06
2038	6.700E+06	5.430E+03	8.139E+06
2039	6.700E+06	5.165E+03	7.742E+06
2040	6.700E+06	4.913E+03	7.364E+06

Methane generation predictions for domestic wastes using CAA parameters for total area of [redacted] Landfill : waste input period 1973 - 2010

		Methane Emission Rate	
Year	Refuse In Place (Mg)	(Mg/yr)	(Cubic m/yr)
2041	6.700E+06	4.673E+03	7.005E+06
2042	6.700E+06	4.445E+03	6.663E+06
2043	6.700E+06	4.229E+03	6.338E+06
2044	6.700E+06	4.022E+03	6.029E+06
2045	6.700E+06	3.826E+03	5.735E+06
2046	6.700E+06	3.640E+03	5.456E+06
2047	6.700E+06	3.462E+03	5.189E+06
2048	6.700E+06	3.293E+03	4.936E+06
2049	6.700E+06	3.133E+03	4.696E+06
2050	6.700E+06	2.980E+03	4.467E+06
2051	6.700E+06	2.835E+03	4.249E+06
2052	6.700E+06	2.696E+03	4.042E+06
2053	6.700E+06	2.565E+03	3.844E+06
2054	6.700E+06	2.440E+03	3.657E+06
2055	6.700E+06	2.321E+03	3.479E+06
2056	6.700E+06	2.208E+03	3.309E+06
2057	6.700E+06	2.100E+03	3.148E+06
2058	6.700E+06	1.997E+03	2.994E+06
2059	6.700E+06	1.900E+03	2.848E+06
2060	6.700E+06	1.807E+03	2.709E+06
2061	6.700E+06	1.719E+03	2.577E+06
2062	6.700E+06	1.635E+03	2.451E+06
2063	6.700E+06	1.556E+03	2.332E+06
2064	6.700E+06	1.480E+03	2.218E+06
2065	6.700E+06	1.408E+03	2.110E+06
2066	6.700E+06	1.339E+03	2.007E+06
2067	6.700E+06	1.274E+03	1.909E+06
2068	6.700E+06	1.212E+03	1.816E+06
2069	6.700E+06	1.152E+03	1.727E+06
2070	6.700E+06	1.096E+03	1.643E+06
2071	6.700E+06	1.043E+03	1.563E+06
2072	6.700E+06	9.919E+02	1.487E+06
2073	6.700E+06	9.435E+02	1.414E+06
2074	6.700E+06	8.975E+02	1.345E+06
2075	6.700E+06	8.537E+02	1.280E+06
2076	6.700E+06	8.121E+02	1.217E+06
2077	6.700E+06	7.725E+02	1.158E+06
2078	6.700E+06	7.348E+02	1.101E+06
2079	6.700E+06	6.990E+02	1.048E+06
2080	6.700E+06	6.649E+02	9.966E+05
2081	6.700E+06	6.325E+02	9.480E+05

Methane generation predictions for domestic wastes using CAA parameters for total area of [redacted] Landfill : waste input period 1973 - 2010

Year	Refuse In Place (Mg)	Methane Emission Rate (Mg/yr)	(Cubic m/yr)
2082	6.700E+06	6.016E+02	9.018E+05
2083	6.700E+06	5.723E+02	8.578E+05
2084	6.700E+06	5.444E+02	8.160E+05
2085	6.700E+06	5.178E+02	7.762E+05
2086	6.700E+06	4.926E+02	7.383E+05
2087	6.700E+06	4.685E+02	7.023E+05
2088	6.700E+06	4.457E+02	6.681E+05
2089	6.700E+06	4.240E+02	6.355E+05
2090	6.700E+06	4.033E+02	6.045E+05
2091	6.700E+06	3.836E+02	5.750E+05
2092	6.700E+06	3.649E+02	5.470E+05
2093	6.700E+06	3.471E+02	5.203E+05
2094	6.700E+06	3.302E+02	4.949E+05
2095	6.700E+06	3.141E+02	4.708E+05
2096	6.700E+06	2.988E+02	4.478E+05
2097	6.700E+06	2.842E+02	4.260E+05
2098	6.700E+06	2.703E+02	4.052E+05
2099	6.700E+06	2.571E+02	3.854E+05
2100	6.700E+06	2.446E+02	3.666E+05
2101	6.700E+06	2.327E+02	3.488E+05
2102	6.700E+06	2.213E+02	3.317E+05
2103	6.700E+06	2.105E+02	3.156E+05
2104	6.700E+06	2.003E+02	3.002E+05
2105	6.700E+06	1.905E+02	2.855E+05
2106	6.700E+06	1.812E+02	2.716E+05
2107	6.700E+06	1.724E+02	2.584E+05
2108	6.700E+06	1.640E+02	2.458E+05
2109	6.700E+06	1.560E+02	2.338E+05
2110	6.700E+06	1.484E+02	2.224E+05
2111	6.700E+06	1.411E+02	2.115E+05
2112	6.700E+06	1.342E+02	2.012E+05
2113	6.700E+06	1.277E+02	1.914E+05
2114	6.700E+06	1.215E+02	1.821E+05
2115	6.700E+06	1.155E+02	1.732E+05
2116	6.700E+06	1.099E+02	1.647E+05
2117	6.700E+06	1.045E+02	1.567E+05
2118	6.700E+06	9.945E+01	1.491E+05
2119	6.700E+06	9.460E+01	1.418E+05
2120	6.700E+06	8.998E+01	1.349E+05
2121	6.700E+06	8.560E+01	1.283E+05
2122	6.700E+06	8.142E+01	1.220E+05

Methane generation predictions for domestic wastes using CAA parameters for total area of [redacted] Landfill : waste input period 1973 - 2010

Year	Refuse In Place (Mg)	Methane Emission Rate (Mg/yr)	(Cubic m/yr)
2123	6.700E+06	7.745E+01	1.161E+05
2124	6.700E+06	7.367E+01	1.104E+05
2125	6.700E+06	7.008E+01	1.050E+05
2126	6.700E+06	6.666E+01	9.992E+04
2127	6.700E+06	6.341E+01	9.505E+04
2128	6.700E+06	6.032E+01	9.041E+04
2129	6.700E+06	5.738E+01	8.600E+04
2130	6.700E+06	5.458E+01	8.181E+04
2131	6.700E+06	5.192E+01	7.782E+04
2132	6.700E+06	4.938E+01	7.402E+04
2133	6.700E+06	4.698E+01	7.041E+04
2134	6.700E+06	4.469E+01	6.698E+04
2135	6.700E+06	4.251E+01	6.371E+04
2136	6.700E+06	4.043E+01	6.061E+04
2137	6.700E+06	3.846E+01	5.765E+04
2138	6.700E+06	3.658E+01	5.484E+04
2139	6.700E+06	3.480E+01	5.216E+04
2140	6.700E+06	3.310E+01	4.962E+04
2141	6.700E+06	3.149E+01	4.720E+04
2142	6.700E+06	2.995E+01	4.490E+04
2143	6.700E+06	2.849E+01	4.271E+04
2144	6.700E+06	2.710E+01	4.062E+04
2145	6.700E+06	2.578E+01	3.864E+04
2146	6.700E+06	2.452E+01	3.676E+04
2147	6.700E+06	2.333E+01	3.497E+04
2148	6.700E+06	2.219E+01	3.326E+04
2149	6.700E+06	2.111E+01	3.164E+04
2150	6.700E+06	2.008E+01	3.010E+04
2151	6.700E+06	1.910E+01	2.863E+04
2152	6.700E+06	1.817E+01	2.723E+04
2153	6.700E+06	1.728E+01	2.590E+04
2154	6.700E+06	1.644E+01	2.464E+04
2155	6.700E+06	1.564E+01	2.344E+04
2156	6.700E+06	1.487E+01	2.230E+04
2157	6.700E+06	1.415E+01	2.121E+04
2158	6.700E+06	1.346E+01	2.017E+04
2159	6.700E+06	1.280E+01	1.919E+04
2160	6.700E+06	1.218E+01	1.825E+04
2161	6.700E+06	1.158E+01	1.736E+04
2162	6.700E+06	1.102E+01	1.652E+04
2163	6.700E+06	1.048E+01	1.571E+04

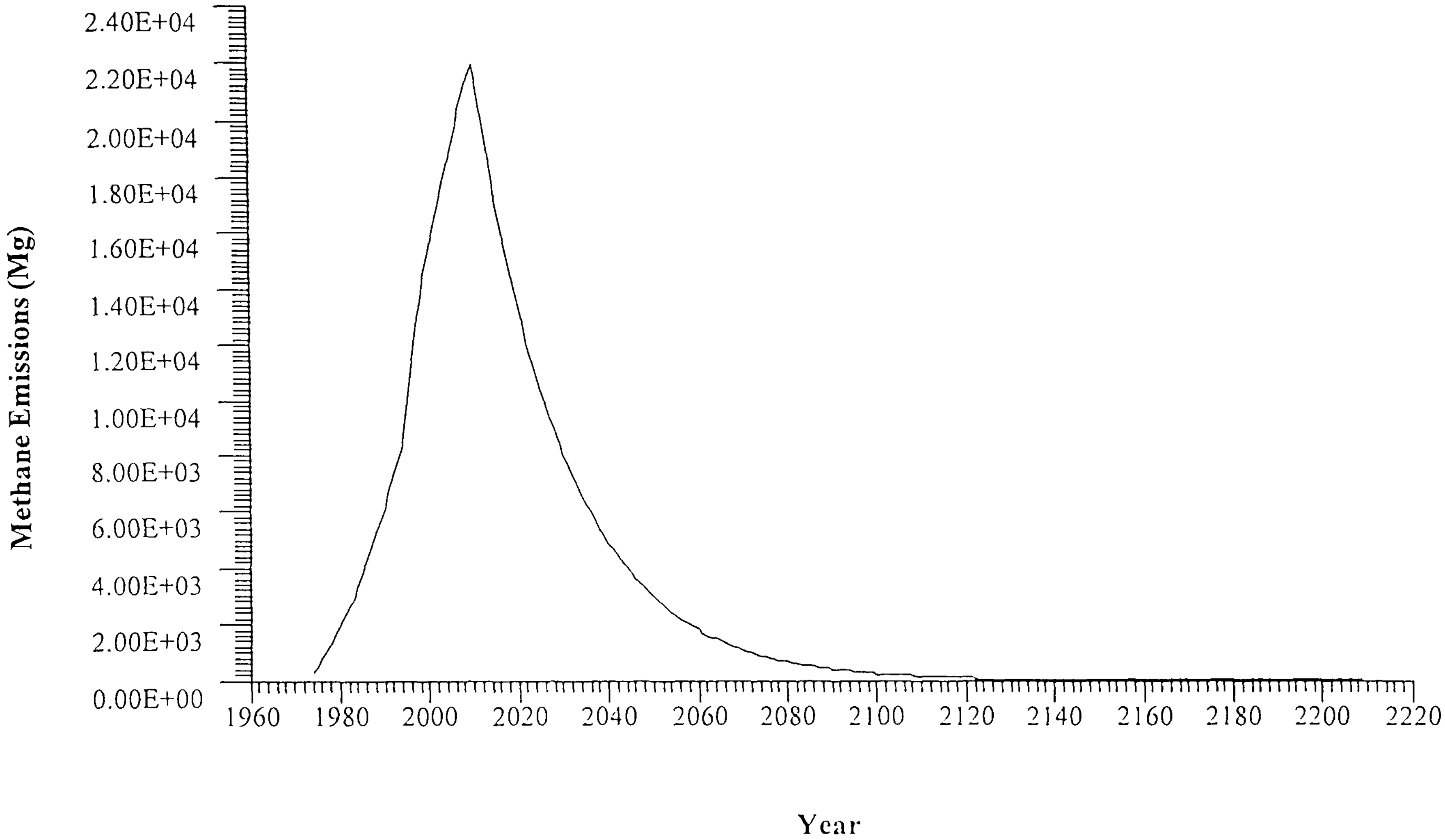
Methane generation predictions for domestic wastes using CAA parameters for total area of [redacted] Landfill : waste input period 1973 - 2010

Year	Refuse In Place (Mg)	Methane Emission Rate (Mg/yr)	(Cubic m/yr)
2164	6.700E+06	9.971E+00	1.495E+04
2165	6.700E+06	9.484E+00	1.422E+04
2166	6.700E+06	9.022E+00	1.352E+04
2167	6.700E+06	8.582E+00	1.286E+04
2168	6.700E+06	8.163E+00	1.224E+04
2169	6.700E+06	7.765E+00	1.164E+04
2170	6.700E+06	7.386E+00	1.107E+04
2171	6.700E+06	7.026E+00	1.053E+04
2172	6.700E+06	6.683E+00	1.002E+04
2173	6.700E+06	6.358E+00	9.529E+03
2174	6.700E+06	6.047E+00	9.065E+03
2175	6.700E+06	5.753E+00	8.623E+03
2176	6.700E+06	5.472E+00	8.202E+03
2177	6.700E+06	5.205E+00	7.802E+03
2178	6.700E+06	4.951E+00	7.421E+03
2179	6.700E+06	4.710E+00	7.060E+03
2180	6.700E+06	4.480E+00	6.715E+03
2181	6.700E+06	4.262E+00	6.388E+03
2182	6.700E+06	4.054E+00	6.076E+03
2183	6.700E+06	3.856E+00	5.780E+03
2184	6.700E+06	3.668E+00	5.498E+03
2185	6.700E+06	3.489E+00	5.230E+03
2186	6.700E+06	3.319E+00	4.975E+03
2187	6.700E+06	3.157E+00	4.732E+03
2188	6.700E+06	3.003E+00	4.501E+03
2189	6.700E+06	2.857E+00	4.282E+03
2190	6.700E+06	2.717E+00	4.073E+03
2191	6.700E+06	2.585E+00	3.874E+03
2192	6.700E+06	2.459E+00	3.685E+03
2193	6.700E+06	2.339E+00	3.506E+03
2194	6.700E+06	2.225E+00	3.335E+03
2195	6.700E+06	2.116E+00	3.172E+03
2196	6.700E+06	2.013E+00	3.017E+03
2197	6.700E+06	1.915E+00	2.870E+03
2198	6.700E+06	1.821E+00	2.730E+03
2199	6.700E+06	1.733E+00	2.597E+03
2200	6.700E+06	1.648E+00	2.470E+03
2201	6.700E+06	1.568E+00	2.350E+03
2202	6.700E+06	1.491E+00	2.235E+03
2203	6.700E+06	1.419E+00	2.126E+03
2204	6.700E+06	1.349E+00	2.023E+03

Methane generation predictions for domestic wastes using CAA parameters for total area of [redacted] Landfill : waste input period 1973 - 2010

		Methane Emission Rate	
Year	Refuse In Place (Mg)	(Mg/yr)	(Cubic m/yr)
2205	6.700E+06	1.284E+00	1.924E+03
2206	6.700E+06	1.221E+00	1.830E+03
2207	6.700E+06	1.161E+00	1.741E+03
2208	6.700E+06	1.105E+00	1.656E+03
2209	6.700E+06	1.051E+00	1.575E+03

Projected Methane Emissions for domestic waste using CAA parameters for total area of landfill



Carbon dioxide generation predictions for domestic wastes using CAA parameters for total area of [redacted] Landfill : waste input period 1973 -2010

Model Parameters

Lo : 170.00 m^3 / Mg
k : 0.0500 1/yr
NMOC : 4000.00 ppmv
Methane : 50.0000 % volume
Carbon Dioxide : 50.0000 % volume

Landfill Parameters

Landfill type : No Co-Disposal
Year Opened : 1973 Current Year : 2010 Closure Year: 2010
Capacity : 6700000 Mg
Average Acceptance Rate Required from
Current Year to Closure Year : 0.00 Mg/year

Model Results

Year	Refuse In Place (Mg)	Carbon Dioxide Emission Rate (Mg/yr)	(Cubic m/yr)
1974	5.000E+04	7.780E+02	4.250E+05
1975	1.000E+05	1.518E+03	8.293E+05
1976	1.500E+05	2.222E+03	1.214E+06
1977	2.000E+05	2.892E+03	1.580E+06
1978	2.500E+05	3.528E+03	1.928E+06
1979	3.250E+05	4.523E+03	2.471E+06
1980	4.000E+05	5.470E+03	2.988E+06
1981	4.750E+05	6.370E+03	3.480E+06
1982	5.500E+05	7.226E+03	3.948E+06
1983	6.250E+05	8.041E+03	4.393E+06
1984	7.250E+05	9.204E+03	5.028E+06
1985	8.250E+05	1.031E+04	5.633E+06
1986	9.500E+05	1.175E+04	6.421E+06
1987	1.075E+06	1.313E+04	7.170E+06
1988	1.200E+06	1.443E+04	7.883E+06
1989	1.325E+06	1.567E+04	8.561E+06
1990	1.450E+06	1.685E+04	9.206E+06
1991	1.600E+06	1.836E+04	1.003E+07
1992	1.750E+06	1.980E+04	1.082E+07
1993	1.900E+06	2.117E+04	1.157E+07
1994	2.070E+06	2.278E+04	1.245E+07
1995	2.420E+06	2.712E+04	1.481E+07
1996	2.770E+06	3.124E+04	1.707E+07
1997	3.120E+06	3.516E+04	1.921E+07
1998	3.385E+06	3.757E+04	2.052E+07
1999	3.650E+06	3.986E+04	2.178E+07

Carbon dioxide generation predictions for domestic wastes using CAA parameters for total area of [redacted] Landfill : waste input period 1973 -2010

		Carbon Dioxide Emission Rate	
Year	Refuse In Place (Mg)	(Mg/yr)	(Cubic m/yr)
2000	3.915E+06	4.204E+04	2.297E+07
2001	4.195E+06	4.435E+04	2.423E+07
2002	4.475E+06	4.654E+04	2.543E+07
2003	4.755E+06	4.863E+04	2.657E+07
2004	5.035E+06	5.061E+04	2.765E+07
2005	5.315E+06	5.250E+04	2.868E+07
2006	5.595E+06	5.430E+04	2.966E+07
2007	5.875E+06	5.601E+04	3.060E+07
2008	6.155E+06	5.763E+04	3.148E+07
2009	6.435E+06	5.918E+04	3.233E+07
2010	6.700E+06	6.041E+04	3.300E+07
2011	6.700E+06	5.747E+04	3.139E+07
2012	6.700E+06	5.466E+04	2.986E+07
2013	6.700E+06	5.200E+04	2.841E+07
2014	6.700E+06	4.946E+04	2.702E+07
2015	6.700E+06	4.705E+04	2.570E+07
2016	6.700E+06	4.476E+04	2.445E+07
2017	6.700E+06	4.257E+04	2.326E+07
2018	6.700E+06	4.050E+04	2.212E+07
2019	6.700E+06	3.852E+04	2.104E+07
2020	6.700E+06	3.664E+04	2.002E+07
2021	6.700E+06	3.486E+04	1.904E+07
2022	6.700E+06	3.316E+04	1.811E+07
2023	6.700E+06	3.154E+04	1.723E+07
2024	6.700E+06	3.000E+04	1.639E+07
2025	6.700E+06	2.854E+04	1.559E+07
2026	6.700E+06	2.715E+04	1.483E+07
2027	6.700E+06	2.582E+04	1.411E+07
2028	6.700E+06	2.456E+04	1.342E+07
2029	6.700E+06	2.336E+04	1.276E+07
2030	6.700E+06	2.222E+04	1.214E+07
2031	6.700E+06	2.114E+04	1.155E+07
2032	6.700E+06	2.011E+04	1.099E+07
2033	6.700E+06	1.913E+04	1.045E+07
2034	6.700E+06	1.820E+04	9.941E+06
2035	6.700E+06	1.731E+04	9.456E+06
2036	6.700E+06	1.646E+04	8.995E+06
2037	6.700E+06	1.566E+04	8.556E+06
2038	6.700E+06	1.490E+04	8.139E+06
2039	6.700E+06	1.417E+04	7.742E+06
2040	6.700E+06	1.348E+04	7.364E+06

Carbon dioxide generation predictions for domestic wastes using CAA parameters for total area of [redacted] Landfill : waste input period 1973 -2010

Year	Refuse In Place (Mg)	Carbon Dioxide Emission Rate (Mg/yr)	(Cubic m/yr)
2041	6.700E+06	1.282E+04	7.005E+06
2042	6.700E+06	1.220E+04	6.663E+06
2043	6.700E+06	1.160E+04	6.338E+06
2044	6.700E+06	1.104E+04	6.029E+06
2045	6.700E+06	1.050E+04	5.735E+06
2046	6.700E+06	9.986E+03	5.456E+06
2047	6.700E+06	9.499E+03	5.189E+06
2048	6.700E+06	9.036E+03	4.936E+06
2049	6.700E+06	8.595E+03	4.696E+06
2050	6.700E+06	8.176E+03	4.467E+06
2051	6.700E+06	7.777E+03	4.249E+06
2052	6.700E+06	7.398E+03	4.042E+06
2053	6.700E+06	7.037E+03	3.844E+06
2054	6.700E+06	6.694E+03	3.657E+06
2055	6.700E+06	6.368E+03	3.479E+06
2056	6.700E+06	6.057E+03	3.309E+06
2057	6.700E+06	5.762E+03	3.148E+06
2058	6.700E+06	5.481E+03	2.994E+06
2059	6.700E+06	5.213E+03	2.848E+06
2060	6.700E+06	4.959E+03	2.709E+06
2061	6.700E+06	4.717E+03	2.577E+06
2062	6.700E+06	4.487E+03	2.451E+06
2063	6.700E+06	4.268E+03	2.332E+06
2064	6.700E+06	4.060E+03	2.218E+06
2065	6.700E+06	3.862E+03	2.110E+06
2066	6.700E+06	3.674E+03	2.007E+06
2067	6.700E+06	3.495E+03	1.909E+06
2068	6.700E+06	3.324E+03	1.816E+06
2069	6.700E+06	3.162E+03	1.727E+06
2070	6.700E+06	3.008E+03	1.643E+06
2071	6.700E+06	2.861E+03	1.563E+06
2072	6.700E+06	2.722E+03	1.487E+06
2073	6.700E+06	2.589E+03	1.414E+06
2074	6.700E+06	2.463E+03	1.345E+06
2075	6.700E+06	2.342E+03	1.280E+06
2076	6.700E+06	2.228E+03	1.217E+06
2077	6.700E+06	2.120E+03	1.158E+06
2078	6.700E+06	2.016E+03	1.101E+06
2079	6.700E+06	1.918E+03	1.048E+06
2080	6.700E+06	1.824E+03	9.966E+05
2081	6.700E+06	1.735E+03	9.480E+05

Carbon dioxide generation predictions for domestic wastes using CAA parameters for total area of [redacted] Landfill : waste input period 1973 -2010

Year	Refuse In Place (Mg)	Carbon Dioxide Emission Rate (Mg/yr)	(Cubic m/yr)
2082	6.700E+06	1.651E+03	9.018E+05
2083	6.700E+06	1.570E+03	8.578E+05
2084	6.700E+06	1.494E+03	8.160E+05
2085	6.700E+06	1.421E+03	7.762E+05
2086	6.700E+06	1.351E+03	7.383E+05
2087	6.700E+06	1.286E+03	7.023E+05
2088	6.700E+06	1.223E+03	6.681E+05
2089	6.700E+06	1.163E+03	6.355E+05
2090	6.700E+06	1.107E+03	6.045E+05
2091	6.700E+06	1.053E+03	5.750E+05
2092	6.700E+06	1.001E+03	5.470E+05
2093	6.700E+06	9.524E+02	5.203E+05
2094	6.700E+06	9.059E+02	4.949E+05
2095	6.700E+06	8.618E+02	4.708E+05
2096	6.700E+06	8.197E+02	4.478E+05
2097	6.700E+06	7.797E+02	4.260E+05
2098	6.700E+06	7.417E+02	4.052E+05
2099	6.700E+06	7.055E+02	3.854E+05
2100	6.700E+06	6.711E+02	3.666E+05
2101	6.700E+06	6.384E+02	3.488E+05
2102	6.700E+06	6.073E+02	3.317E+05
2103	6.700E+06	5.777E+02	3.156E+05
2104	6.700E+06	5.495E+02	3.002E+05
2105	6.700E+06	5.227E+02	2.855E+05
2106	6.700E+06	4.972E+02	2.716E+05
2107	6.700E+06	4.729E+02	2.584E+05
2108	6.700E+06	4.499E+02	2.458E+05
2109	6.700E+06	4.279E+02	2.338E+05
2110	6.700E+06	4.071E+02	2.224E+05
2111	6.700E+06	3.872E+02	2.115E+05
2112	6.700E+06	3.683E+02	2.012E+05
2113	6.700E+06	3.504E+02	1.914E+05
2114	6.700E+06	3.333E+02	1.821E+05
2115	6.700E+06	3.170E+02	1.732E+05
2116	6.700E+06	3.016E+02	1.647E+05
2117	6.700E+06	2.869E+02	1.567E+05
2118	6.700E+06	2.729E+02	1.491E+05
2119	6.700E+06	2.596E+02	1.418E+05
2120	6.700E+06	2.469E+02	1.349E+05
2121	6.700E+06	2.349E+02	1.283E+05
2122	6.700E+06	2.234E+02	1.220E+05

Carbon dioxide generation predictions for domestic wastes using CAA parameters for total area of [redacted] Landfill : waste input period 1973 -2010

Year	Refuse In Place (Mg)	Carbon Dioxide Emission Rate (Mg/yr)	(Cubic m/yr)
2123	6.700E+06	2.125E+02	1.161E+05
2124	6.700E+06	2.021E+02	1.104E+05
2125	6.700E+06	1.923E+02	1.050E+05
2126	6.700E+06	1.829E+02	9.992E+04
2127	6.700E+06	1.740E+02	9.505E+04
2128	6.700E+06	1.655E+02	9.041E+04
2129	6.700E+06	1.574E+02	8.600E+04
2130	6.700E+06	1.498E+02	8.181E+04
2131	6.700E+06	1.424E+02	7.782E+04
2132	6.700E+06	1.355E+02	7.402E+04
2133	6.700E+06	1.289E+02	7.041E+04
2134	6.700E+06	1.226E+02	6.698E+04
2135	6.700E+06	1.166E+02	6.371E+04
2136	6.700E+06	1.109E+02	6.061E+04
2137	6.700E+06	1.055E+02	5.765E+04
2138	6.700E+06	1.004E+02	5.484E+04
2139	6.700E+06	9.549E+01	5.216E+04
2140	6.700E+06	9.083E+01	4.962E+04
2141	6.700E+06	8.640E+01	4.720E+04
2142	6.700E+06	8.218E+01	4.490E+04
2143	6.700E+06	7.818E+01	4.271E+04
2144	6.700E+06	7.436E+01	4.062E+04
2145	6.700E+06	7.074E+01	3.864E+04
2146	6.700E+06	6.729E+01	3.676E+04
2147	6.700E+06	6.401E+01	3.497E+04
2148	6.700E+06	6.088E+01	3.326E+04
2149	6.700E+06	5.791E+01	3.164E+04
2150	6.700E+06	5.509E+01	3.010E+04
2151	6.700E+06	5.240E+01	2.863E+04
2152	6.700E+06	4.985E+01	2.723E+04
2153	6.700E+06	4.742E+01	2.590E+04
2154	6.700E+06	4.510E+01	2.464E+04
2155	6.700E+06	4.290E+01	2.344E+04
2156	6.700E+06	4.081E+01	2.230E+04
2157	6.700E+06	3.882E+01	2.121E+04
2158	6.700E+06	3.693E+01	2.017E+04
2159	6.700E+06	3.513E+01	1.919E+04
2160	6.700E+06	3.341E+01	1.825E+04
2161	6.700E+06	3.178E+01	1.736E+04
2162	6.700E+06	3.023E+01	1.652E+04
2163	6.700E+06	2.876E+01	1.571E+04

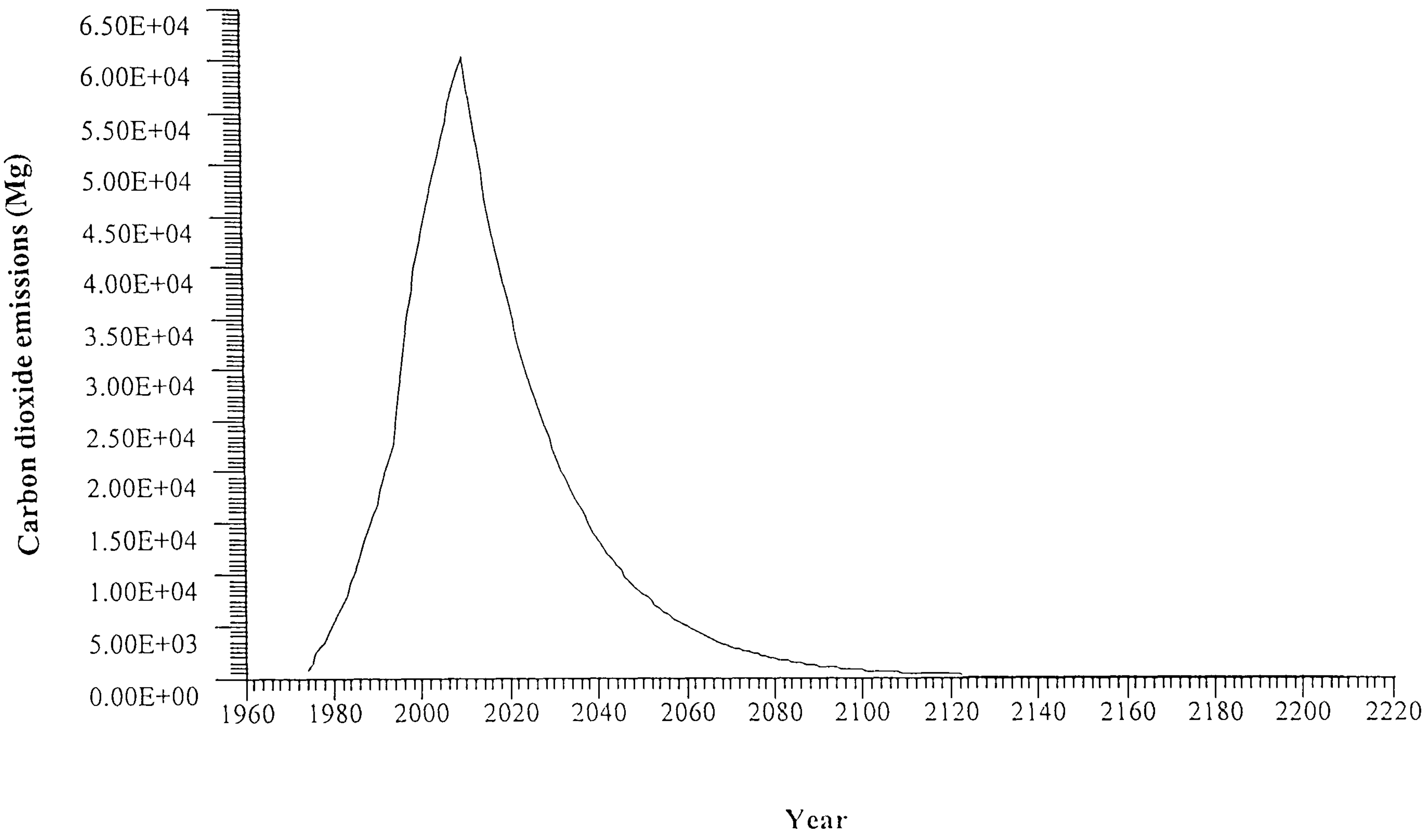
Carbon dioxide generation predictions for domestic wastes using CAA parameters for total area of [redacted] Landfill : waste input period 1973 -2010

Year	Refuse In Place (Mg)	Carbon Dioxide Emission Rate (Mg/yr)	(Cubic m/yr)
2164	6.700E+06	2.736E+01	1.495E+04
2165	6.700E+06	2.602E+01	1.422E+04
2166	6.700E+06	2.475E+01	1.352E+04
2167	6.700E+06	2.355E+01	1.286E+04
2168	6.700E+06	2.240E+01	1.224E+04
2169	6.700E+06	2.131E+01	1.164E+04
2170	6.700E+06	2.027E+01	1.107E+04
2171	6.700E+06	1.928E+01	1.053E+04
2172	6.700E+06	1.834E+01	1.002E+04
2173	6.700E+06	1.744E+01	9.529E+03
2174	6.700E+06	1.659E+01	9.065E+03
2175	6.700E+06	1.578E+01	8.623E+03
2176	6.700E+06	1.501E+01	8.202E+03
2177	6.700E+06	1.428E+01	7.802E+03
2178	6.700E+06	1.359E+01	7.421E+03
2179	6.700E+06	1.292E+01	7.060E+03
2180	6.700E+06	1.229E+01	6.715E+03
2181	6.700E+06	1.169E+01	6.388E+03
2182	6.700E+06	1.112E+01	6.076E+03
2183	6.700E+06	1.058E+01	5.780E+03
2184	6.700E+06	1.006E+01	5.498E+03
2185	6.700E+06	9.573E+00	5.230E+03
2186	6.700E+06	9.106E+00	4.975E+03
2187	6.700E+06	8.662E+00	4.732E+03
2188	6.700E+06	8.240E+00	4.501E+03
2189	6.700E+06	7.838E+00	4.282E+03
2190	6.700E+06	7.456E+00	4.073E+03
2191	6.700E+06	7.092E+00	3.874E+03
2192	6.700E+06	6.746E+00	3.685E+03
2193	6.700E+06	6.417E+00	3.506E+03
2194	6.700E+06	6.104E+00	3.335E+03
2195	6.700E+06	5.806E+00	3.172E+03
2196	6.700E+06	5.523E+00	3.017E+03
2197	6.700E+06	5.254E+00	2.870E+03
2198	6.700E+06	4.998E+00	2.730E+03
2199	6.700E+06	4.754E+00	2.597E+03
2200	6.700E+06	4.522E+00	2.470E+03
2201	6.700E+06	4.302E+00	2.350E+03
2202	6.700E+06	4.092E+00	2.235E+03
2203	6.700E+06	3.892E+00	2.126E+03
2204	6.700E+06	3.702E+00	2.023E+03

Carbon dioxide generation predictions for domestic wastes using CAA parameters for total area of [redacted] Landfill : waste input period 1973 -2010

Year	Refuse In Place (Mg)	Carbon Dioxide Emission Rate (Mg/yr)	Carbon Dioxide Emission Rate (Cubic m/yr)
2205	6.700E+06	3.522E+00	1.924E+03
2206	6.700E+06	3.350E+00	1.830E+03
2207	6.700E+06	3.187E+00	1.741E+03
2208	6.700E+06	3.031E+00	1.656E+03
2209	6.700E+06	2.883E+00	1.575E+03

Projected Carbon Dioxide Emissions for domestic waste using CAA parameters for total area of Landfill



APPENDIX F

Model 3A - [redacted] Total Waste Volume (Co-disposal - no adjustment for inerts)

Methane generation predictions for co-disposal wastes using CAA parameters for total area of [redacted] Landfill : waste input period 1973 -2010

Model Parameters

Lo : 170.00 m^3 / Mg
k : 0.0500 1/yr
NMOC : 4000.00 ppmv
Methane : 50.0000 % volume
Carbon Dioxide : 50.0000 % volume

Landfill Parameters

Landfill type : Co-Disposal
Year Opened : 1973 Current Year : 2010 Closure Year: 2010
Capacity : 6700000 Mg
Average Acceptance Rate Required from
Current Year to Closure Year : 0.00 Mg/year

Model Results

Year	Refuse In Place (Mg)	Methane Emission Rate (Mg/yr)	Methane Emission Rate (Cubic m/yr)
1974	5.000E+04	2.835E+02	4.250E+05
1975	1.000E+05	5.532E+02	8.293E+05
1976	1.500E+05	8.098E+02	1.214E+06
1977	2.000E+05	1.054E+03	1.580E+06
1978	2.500E+05	1.286E+03	1.928E+06
1979	3.250E+05	1.649E+03	2.471E+06
1980	4.000E+05	1.993E+03	2.988E+06
1981	4.750E+05	2.322E+03	3.480E+06
1982	5.500E+05	2.634E+03	3.948E+06
1983	6.250E+05	2.931E+03	4.393E+06
1984	7.250E+05	3.355E+03	5.028E+06
1985	8.250E+05	3.758E+03	5.633E+06
1986	9.500E+05	4.284E+03	6.421E+06
1987	1.075E+06	4.784E+03	7.170E+06
1988	1.200E+06	5.259E+03	7.883E+06
1989	1.325E+06	5.712E+03	8.561E+06
1990	1.450E+06	6.142E+03	9.206E+06
1991	1.600E+06	6.693E+03	1.003E+07
1992	1.750E+06	7.217E+03	1.082E+07
1993	1.900E+06	7.716E+03	1.157E+07
1994	2.070E+06	8.303E+03	1.245E+07
1995	2.420E+06	9.883E+03	1.481E+07
1996	2.770E+06	1.139E+04	1.707E+07
1997	3.120E+06	1.282E+04	1.921E+07
1998	3.385E+06	1.369E+04	2.052E+07
1999	3.650E+06	1.453E+04	2.178E+07

Methane generation predictions for co-disposal wastes using CAA parameters for total area of [redacted] Landfill : waste input period 1973 -2010

Year	Refuse In Place (Mg)	Methane Emission Rate (Mg/yr)	(Cubic m/yr)
2000	3.915E+06	1.532E+04	2.297E+07
2001	4.195E+06	1.616E+04	2.423E+07
2002	4.475E+06	1.696E+04	2.543E+07
2003	4.755E+06	1.772E+04	2.657E+07
2004	5.035E+06	1.845E+04	2.765E+07
2005	5.315E+06	1.913E+04	2.868E+07
2006	5.595E+06	1.979E+04	2.966E+07
2007	5.875E+06	2.041E+04	3.060E+07
2008	6.155E+06	2.100E+04	3.148E+07
2009	6.435E+06	2.157E+04	3.233E+07
2010	6.700E+06	2.202E+04	3.300E+07
2011	6.700E+06	2.094E+04	3.139E+07
2012	6.700E+06	1.992E+04	2.986E+07
2013	6.700E+06	1.895E+04	2.841E+07
2014	6.700E+06	1.803E+04	2.702E+07
2015	6.700E+06	1.715E+04	2.570E+07
2016	6.700E+06	1.631E+04	2.445E+07
2017	6.700E+06	1.552E+04	2.326E+07
2018	6.700E+06	1.476E+04	2.212E+07
2019	6.700E+06	1.404E+04	2.104E+07
2020	6.700E+06	1.335E+04	2.002E+07
2021	6.700E+06	1.270E+04	1.904E+07
2022	6.700E+06	1.208E+04	1.811E+07
2023	6.700E+06	1.149E+04	1.723E+07
2024	6.700E+06	1.093E+04	1.639E+07
2025	6.700E+06	1.040E+04	1.559E+07
2026	6.700E+06	9.894E+03	1.483E+07
2027	6.700E+06	9.411E+03	1.411E+07
2028	6.700E+06	8.952E+03	1.342E+07
2029	6.700E+06	8.515E+03	1.276E+07
2030	6.700E+06	8.100E+03	1.214E+07
2031	6.700E+06	7.705E+03	1.155E+07
2032	6.700E+06	7.329E+03	1.099E+07
2033	6.700E+06	6.972E+03	1.045E+07
2034	6.700E+06	6.632E+03	9.941E+06
2035	6.700E+06	6.308E+03	9.456E+06
2036	6.700E+06	6.001E+03	8.995E+06
2037	6.700E+06	5.708E+03	8.556E+06
2038	6.700E+06	5.430E+03	8.139E+06
2039	6.700E+06	5.165E+03	7.742E+06
2040	6.700E+06	4.913E+03	7.364E+06

Methane generation predictions for co-disposal wastes using CAA parameters for total area of [redacted] Landfill : waste input period 1973 -2010

		Methane Emission Rate	
Year	Refuse In Place (Mg)	(Mg/yr)	(Cubic m/yr)
2041	6.700E+06	4.673E+03	7.005E+06
2042	6.700E+06	4.445E+03	6.663E+06
2043	6.700E+06	4.229E+03	6.338E+06
2044	6.700E+06	4.022E+03	6.029E+06
2045	6.700E+06	3.826E+03	5.735E+06
2046	6.700E+06	3.640E+03	5.456E+06
2047	6.700E+06	3.462E+03	5.189E+06
2048	6.700E+06	3.293E+03	4.936E+06
2049	6.700E+06	3.133E+03	4.696E+06
2050	6.700E+06	2.980E+03	4.467E+06
2051	6.700E+06	2.835E+03	4.249E+06
2052	6.700E+06	2.696E+03	4.042E+06
2053	6.700E+06	2.565E+03	3.844E+06
2054	6.700E+06	2.440E+03	3.657E+06
2055	6.700E+06	2.321E+03	3.479E+06
2056	6.700E+06	2.208E+03	3.309E+06
2057	6.700E+06	2.100E+03	3.148E+06
2058	6.700E+06	1.997E+03	2.994E+06
2059	6.700E+06	1.900E+03	2.848E+06
2060	6.700E+06	1.807E+03	2.709E+06
2061	6.700E+06	1.719E+03	2.577E+06
2062	6.700E+06	1.635E+03	2.451E+06
2063	6.700E+06	1.556E+03	2.332E+06
2064	6.700E+06	1.480E+03	2.218E+06
2065	6.700E+06	1.408E+03	2.110E+06
2066	6.700E+06	1.339E+03	2.007E+06
2067	6.700E+06	1.274E+03	1.909E+06
2068	6.700E+06	1.212E+03	1.816E+06
2069	6.700E+06	1.152E+03	1.727E+06
2070	6.700E+06	1.096E+03	1.643E+06
2071	6.700E+06	1.043E+03	1.563E+06
2072	6.700E+06	9.919E+02	1.487E+06
2073	6.700E+06	9.435E+02	1.414E+06
2074	6.700E+06	8.975E+02	1.345E+06
2075	6.700E+06	8.537E+02	1.280E+06
2076	6.700E+06	8.121E+02	1.217E+06
2077	6.700E+06	7.725E+02	1.158E+06
2078	6.700E+06	7.348E+02	1.101E+06
2079	6.700E+06	6.990E+02	1.048E+06
2080	6.700E+06	6.649E+02	9.966E+05
2081	6.700E+06	6.325E+02	9.480E+05

Methane generation predictions for co-disposal wastes using CAA parameters for total area of [redacted] Landfill : waste input period 1973 -2010

Year	Refuse In Place (Mg)	Methane Emission Rate (Mg/yr)	(Cubic m/yr)
2082	6.700E+06	6.016E+02	9.018E+05
2083	6.700E+06	5.723E+02	8.578E+05
2084	6.700E+06	5.444E+02	8.160E+05
2085	6.700E+06	5.178E+02	7.762E+05
2086	6.700E+06	4.926E+02	7.383E+05
2087	6.700E+06	4.685E+02	7.023E+05
2088	6.700E+06	4.457E+02	6.681E+05
2089	6.700E+06	4.240E+02	6.355E+05
2090	6.700E+06	4.033E+02	6.045E+05
2091	6.700E+06	3.836E+02	5.750E+05
2092	6.700E+06	3.649E+02	5.470E+05
2093	6.700E+06	3.471E+02	5.203E+05
2094	6.700E+06	3.302E+02	4.949E+05
2095	6.700E+06	3.141E+02	4.708E+05
2096	6.700E+06	2.988E+02	4.478E+05
2097	6.700E+06	2.842E+02	4.260E+05
2098	6.700E+06	2.703E+02	4.052E+05
2099	6.700E+06	2.571E+02	3.854E+05
2100	6.700E+06	2.446E+02	3.666E+05
2101	6.700E+06	2.327E+02	3.488E+05
2102	6.700E+06	2.213E+02	3.317E+05
2103	6.700E+06	2.105E+02	3.156E+05
2104	6.700E+06	2.003E+02	3.002E+05
2105	6.700E+06	1.905E+02	2.855E+05
2106	6.700E+06	1.812E+02	2.716E+05
2107	6.700E+06	1.724E+02	2.584E+05
2108	6.700E+06	1.640E+02	2.458E+05
2109	6.700E+06	1.560E+02	2.338E+05
2110	6.700E+06	1.484E+02	2.224E+05
2111	6.700E+06	1.411E+02	2.115E+05
2112	6.700E+06	1.342E+02	2.012E+05
2113	6.700E+06	1.277E+02	1.914E+05
2114	6.700E+06	1.215E+02	1.821E+05
2115	6.700E+06	1.155E+02	1.732E+05
2116	6.700E+06	1.099E+02	1.647E+05
2117	6.700E+06	1.045E+02	1.567E+05
2118	6.700E+06	9.945E+01	1.491E+05
2119	6.700E+06	9.460E+01	1.418E+05
2120	6.700E+06	8.998E+01	1.349E+05
2121	6.700E+06	8.560E+01	1.283E+05
2122	6.700E+06	8.142E+01	1.220E+05

Methane generation predictions for co-disposal wastes using CAA parameters for total area of [redacted] Landfill : waste input period 1973 -2010

Year	Refuse In Place (Mg)	Methane Emission Rate (Mg/yr)	(Cubic m/yr)
2123	6.700E+06	7.745E+01	1.161E+05
2124	6.700E+06	7.367E+01	1.104E+05
2125	6.700E+06	7.008E+01	1.050E+05
2126	6.700E+06	6.666E+01	9.992E+04
2127	6.700E+06	6.341E+01	9.505E+04
2128	6.700E+06	6.032E+01	9.041E+04
2129	6.700E+06	5.738E+01	8.600E+04
2130	6.700E+06	5.458E+01	8.181E+04
2131	6.700E+06	5.192E+01	7.782E+04
2132	6.700E+06	4.938E+01	7.402E+04
2133	6.700E+06	4.698E+01	7.041E+04
2134	6.700E+06	4.469E+01	6.698E+04
2135	6.700E+06	4.251E+01	6.371E+04
2136	6.700E+06	4.043E+01	6.061E+04
2137	6.700E+06	3.846E+01	5.765E+04
2138	6.700E+06	3.658E+01	5.484E+04
2139	6.700E+06	3.480E+01	5.216E+04
2140	6.700E+06	3.310E+01	4.962E+04
2141	6.700E+06	3.149E+01	4.720E+04
2142	6.700E+06	2.995E+01	4.490E+04
2143	6.700E+06	2.849E+01	4.271E+04
2144	6.700E+06	2.710E+01	4.062E+04
2145	6.700E+06	2.578E+01	3.864E+04
2146	6.700E+06	2.452E+01	3.676E+04
2147	6.700E+06	2.333E+01	3.497E+04
2148	6.700E+06	2.219E+01	3.326E+04
2149	6.700E+06	2.111E+01	3.164E+04
2150	6.700E+06	2.008E+01	3.010E+04
2151	6.700E+06	1.910E+01	2.863E+04
2152	6.700E+06	1.817E+01	2.723E+04
2153	6.700E+06	1.728E+01	2.590E+04
2154	6.700E+06	1.644E+01	2.464E+04
2155	6.700E+06	1.564E+01	2.344E+04
2156	6.700E+06	1.487E+01	2.230E+04
2157	6.700E+06	1.415E+01	2.121E+04
2158	6.700E+06	1.346E+01	2.017E+04
2159	6.700E+06	1.280E+01	1.919E+04
2160	6.700E+06	1.218E+01	1.825E+04
2161	6.700E+06	1.158E+01	1.736E+04
2162	6.700E+06	1.102E+01	1.652E+04
2163	6.700E+06	1.048E+01	1.571E+04

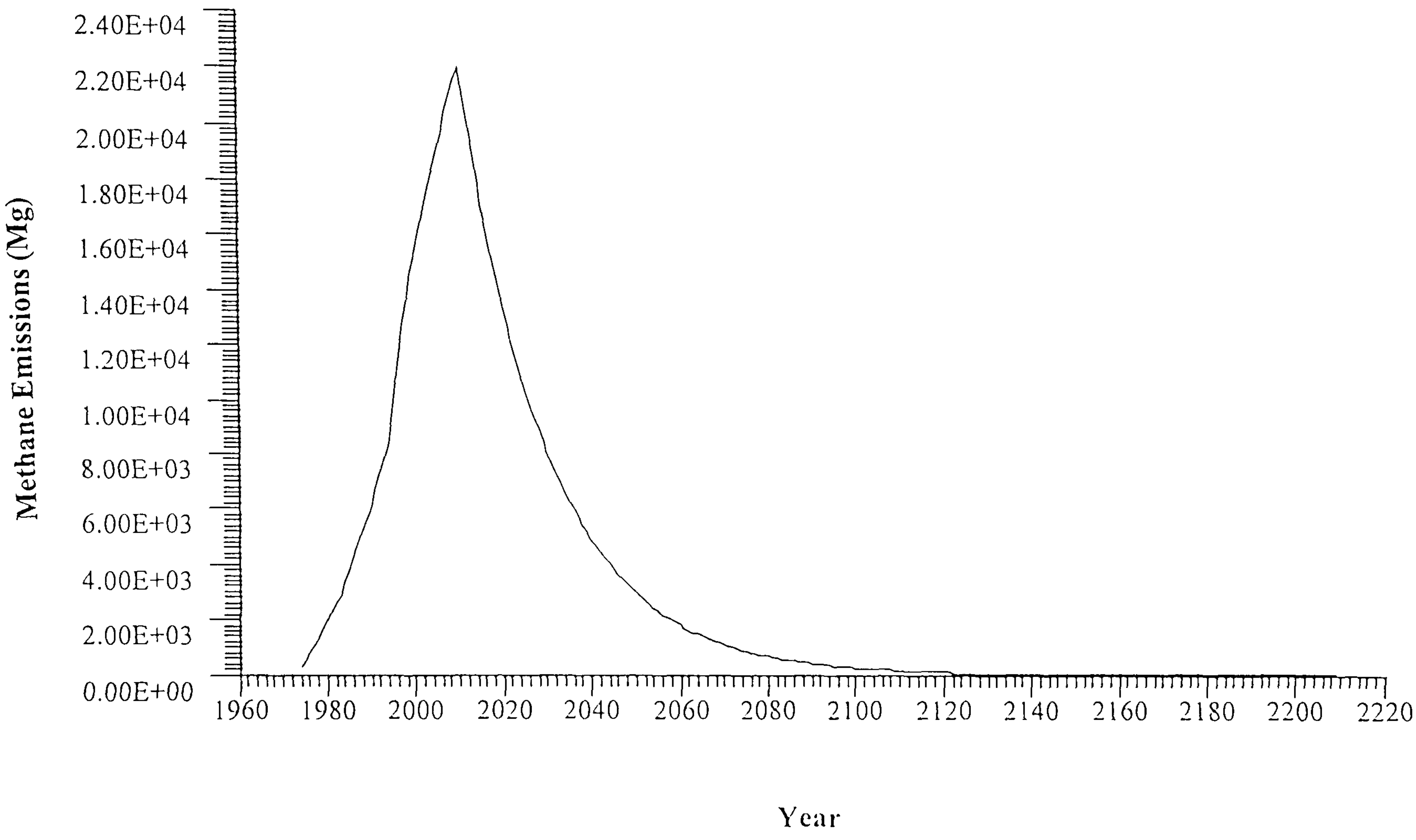
Methane generation predictions for co-disposal wastes using CAA parameters for total area of [redacted] Landfill : waste input period 1973 -2010

Year	Refuse In Place (Mg)	Methane Emission Rate (Mg/yr)	(Cubic m/yr)
2164	6.700E+06	9.971E+00	1.495E+04
2165	6.700E+06	9.484E+00	1.422E+04
2166	6.700E+06	9.022E+00	1.352E+04
2167	6.700E+06	8.582E+00	1.286E+04
2168	6.700E+06	8.163E+00	1.224E+04
2169	6.700E+06	7.765E+00	1.164E+04
2170	6.700E+06	7.386E+00	1.107E+04
2171	6.700E+06	7.026E+00	1.053E+04
2172	6.700E+06	6.683E+00	1.002E+04
2173	6.700E+06	6.358E+00	9.529E+03
2174	6.700E+06	6.047E+00	9.065E+03
2175	6.700E+06	5.753E+00	8.623E+03
2176	6.700E+06	5.472E+00	8.202E+03
2177	6.700E+06	5.205E+00	7.802E+03
2178	6.700E+06	4.951E+00	7.421E+03
2179	6.700E+06	4.710E+00	7.060E+03
2180	6.700E+06	4.480E+00	6.715E+03
2181	6.700E+06	4.262E+00	6.388E+03
2182	6.700E+06	4.054E+00	6.076E+03
2183	6.700E+06	3.856E+00	5.780E+03
2184	6.700E+06	3.668E+00	5.498E+03
2185	6.700E+06	3.489E+00	5.230E+03
2186	6.700E+06	3.319E+00	4.975E+03
2187	6.700E+06	3.157E+00	4.732E+03
2188	6.700E+06	3.003E+00	4.501E+03
2189	6.700E+06	2.857E+00	4.282E+03
2190	6.700E+06	2.717E+00	4.073E+03
2191	6.700E+06	2.585E+00	3.874E+03
2192	6.700E+06	2.459E+00	3.685E+03
2193	6.700E+06	2.339E+00	3.506E+03
2194	6.700E+06	2.225E+00	3.335E+03
2195	6.700E+06	2.116E+00	3.172E+03
2196	6.700E+06	2.013E+00	3.017E+03
2197	6.700E+06	1.915E+00	2.870E+03
2198	6.700E+06	1.821E+00	2.730E+03
2199	6.700E+06	1.733E+00	2.597E+03
2200	6.700E+06	1.648E+00	2.470E+03
2201	6.700E+06	1.568E+00	2.350E+03
2202	6.700E+06	1.491E+00	2.235E+03
2203	6.700E+06	1.419E+00	2.126E+03
2204	6.700E+06	1.349E+00	2.023E+03

Methane generation predictions for co-disposal wastes using CAA parameters for total area of [redacted] Landfill : waste input period 1973 -2010

Year	Refuse In Place (Mg)	Methane Emission Rate (Mg/yr)	(Cubic m/yr)
2205	6.700E+06	1.284E+00	1.924E+03
2206	6.700E+06	1.221E+00	1.830E+03
2207	6.700E+06	1.161E+00	1.741E+03
2208	6.700E+06	1.105E+00	1.656E+03
2209	6.700E+06	1.051E+00	1.575E+03

Projected Methane emissions for co-disposal wastes using CAA parameters for total area of landfill



Carbon dioxide generation predictions for co-disposal wastes using CAA parameters for total area of [redacted] Landfill : waste input period 1973 - 2010

Model Parameters

Lo : 170.00 m^3 / Mg
k : 0.0500 1/yr
NMOC : 4000.00 ppmv
Methane : 50.0000 % volume
Carbon Dioxide : 50.0000 % volume

Landfill Parameters

Landfill Type : Co-Disposal
Year Opened : 1973 Current Year : 2010 Closure Year: 2010
Capacity : 6700000 Mg
Average Acceptance Rate Required from
Current Year to Closure Year : 0.00 Mg/year

Model Results

		Carbon Dioxide Emission Rate	
Year	Refuse In Place (Mg)	(Mg/yr)	(Cubic m/yr)
1974	5.000E+04	7.780E+02	4.250E+05
1975	1.000E+05	1.518E+03	8.293E+05
1976	1.500E+05	2.222E+03	1.214E+06
1977	2.000E+05	2.892E+03	1.580E+06
1978	2.500E+05	3.528E+03	1.928E+06
1979	3.250E+05	4.523E+03	2.471E+06
1980	4.000E+05	5.470E+03	2.988E+06
1981	4.750E+05	6.370E+03	3.480E+06
1982	5.500E+05	7.226E+03	3.948E+06
1983	6.250E+05	8.041E+03	4.393E+06
1984	7.250E+05	9.204E+03	5.028E+06
1985	8.250E+05	1.031E+04	5.633E+06
1986	9.500E+05	1.175E+04	6.421E+06
1987	1.075E+06	1.313E+04	7.170E+06
1988	1.200E+06	1.443E+04	7.883E+06
1989	1.325E+06	1.567E+04	8.561E+06
1990	1.450E+06	1.685E+04	9.206E+06
1991	1.600E+06	1.836E+04	1.003E+07
1992	1.750E+06	1.980E+04	1.082E+07
1993	1.900E+06	2.117E+04	1.157E+07
1994	2.070E+06	2.278E+04	1.245E+07
1995	2.420E+06	2.712E+04	1.481E+07
1996	2.770E+06	3.124E+04	1.707E+07
1997	3.120E+06	3.516E+04	1.921E+07
1998	3.385E+06	3.757E+04	2.052E+07
1999	3.650E+06	3.986E+04	2.178E+07

Carbon dioxide generation predictions for co-disposal wastes using CAA parameters for total area of [redacted] Landfill : waste input period 1973 - 2010

		Carbon Dioxide Emission Rate	
Year	Refuse In Place (Mg)	(Mg/yr)	(Cubic m/yr)
2000	3.915E+06	4.204E+04	2.297E+07
2001	4.195E+06	4.435E+04	2.423E+07
2002	4.475E+06	4.654E+04	2.543E+07
2003	4.755E+06	4.863E+04	2.657E+07
2004	5.035E+06	5.061E+04	2.765E+07
2005	5.315E+06	5.250E+04	2.868E+07
2006	5.595E+06	5.430E+04	2.966E+07
2007	5.875E+06	5.601E+04	3.060E+07
2008	6.155E+06	5.763E+04	3.148E+07
2009	6.435E+06	5.918E+04	3.233E+07
2010	6.700E+06	6.041E+04	3.300E+07
2011	6.700E+06	5.747E+04	3.139E+07
2012	6.700E+06	5.466E+04	2.986E+07
2013	6.700E+06	5.200E+04	2.841E+07
2014	6.700E+06	4.946E+04	2.702E+07
2015	6.700E+06	4.705E+04	2.570E+07
2016	6.700E+06	4.476E+04	2.445E+07
2017	6.700E+06	4.257E+04	2.326E+07
2018	6.700E+06	4.050E+04	2.212E+07
2019	6.700E+06	3.852E+04	2.104E+07
2020	6.700E+06	3.664E+04	2.002E+07
2021	6.700E+06	3.486E+04	1.904E+07
2022	6.700E+06	3.316E+04	1.811E+07
2023	6.700E+06	3.154E+04	1.723E+07
2024	6.700E+06	3.000E+04	1.639E+07
2025	6.700E+06	2.854E+04	1.559E+07
2026	6.700E+06	2.715E+04	1.483E+07
2027	6.700E+06	2.582E+04	1.411E+07
2028	6.700E+06	2.456E+04	1.342E+07
2029	6.700E+06	2.336E+04	1.276E+07
2030	6.700E+06	2.222E+04	1.214E+07
2031	6.700E+06	2.114E+04	1.155E+07
2032	6.700E+06	2.011E+04	1.099E+07
2033	6.700E+06	1.913E+04	1.045E+07
2034	6.700E+06	1.820E+04	9.941E+06
2035	6.700E+06	1.731E+04	9.456E+06
2036	6.700E+06	1.646E+04	8.995E+06
2037	6.700E+06	1.566E+04	8.556E+06
2038	6.700E+06	1.490E+04	8.139E+06
2039	6.700E+06	1.417E+04	7.742E+06
2040	6.700E+06	1.348E+04	7.364E+06
2041	6.700E+06	1.282E+04	7.005E+06

Carbon dioxide generation predictions for co-disposal wastes using CAA parameters for total area of [redacted] Landfill : waste input period 1973 - 2010

		Carbon Dioxide Emission Rate	
Year	Refuse In Place (Mg)	(Mg/yr)	(Cubic m/yr)
2042	6.700E+06	1.220E+04	6.663E+06
2043	6.700E+06	1.160E+04	6.338E+06
2044	6.700E+06	1.104E+04	6.029E+06
2045	6.700E+06	1.050E+04	5.735E+06
2046	6.700E+06	9.986E+03	5.456E+06
2047	6.700E+06	9.499E+03	5.189E+06
2048	6.700E+06	9.036E+03	4.936E+06
2049	6.700E+06	8.595E+03	4.696E+06
2050	6.700E+06	8.176E+03	4.467E+06
2051	6.700E+06	7.777E+03	4.249E+06
2052	6.700E+06	7.398E+03	4.042E+06
2053	6.700E+06	7.037E+03	3.844E+06
2054	6.700E+06	6.694E+03	3.657E+06
2055	6.700E+06	6.368E+03	3.479E+06
2056	6.700E+06	6.057E+03	3.309E+06
2057	6.700E+06	5.762E+03	3.148E+06
2058	6.700E+06	5.481E+03	2.994E+06
2059	6.700E+06	5.213E+03	2.848E+06
2060	6.700E+06	4.959E+03	2.709E+06
2061	6.700E+06	4.717E+03	2.577E+06
2062	6.700E+06	4.487E+03	2.451E+06
2063	6.700E+06	4.268E+03	2.332E+06
2064	6.700E+06	4.060E+03	2.218E+06
2065	6.700E+06	3.862E+03	2.110E+06
2066	6.700E+06	3.674E+03	2.007E+06
2067	6.700E+06	3.495E+03	1.909E+06
2068	6.700E+06	3.324E+03	1.816E+06
2069	6.700E+06	3.162E+03	1.727E+06
2070	6.700E+06	3.008E+03	1.643E+06
2071	6.700E+06	2.861E+03	1.563E+06
2072	6.700E+06	2.722E+03	1.487E+06
2073	6.700E+06	2.589E+03	1.414E+06
2074	6.700E+06	2.463E+03	1.345E+06
2075	6.700E+06	2.342E+03	1.280E+06
2076	6.700E+06	2.228E+03	1.217E+06
2077	6.700E+06	2.120E+03	1.158E+06
2078	6.700E+06	2.016E+03	1.101E+06
2079	6.700E+06	1.918E+03	1.048E+06
2080	6.700E+06	1.824E+03	9.966E+05
2081	6.700E+06	1.735E+03	9.480E+05
2082	6.700E+06	1.651E+03	9.018E+05
2083	6.700E+06	1.570E+03	8.578E+05

Carbon dioxide generation predictions for co-disposal wastes using CAA parameters for total area of [redacted] Landfill : waste input period 1973 - 2010

Year	Refuse In Place (Mg)	Carbon Dioxide Emission Rate (Mg/yr)	(Cubic m/yr)
2084	6.700E+06	1.494E+03	8.160E+05
2085	6.700E+06	1.421E+03	7.762E+05
2086	6.700E+06	1.351E+03	7.383E+05
2087	6.700E+06	1.286E+03	7.023E+05
2088	6.700E+06	1.223E+03	6.681E+05
2089	6.700E+06	1.163E+03	6.355E+05
2090	6.700E+06	1.107E+03	6.045E+05
2091	6.700E+06	1.053E+03	5.750E+05
2092	6.700E+06	1.001E+03	5.470E+05
2093	6.700E+06	9.524E+02	5.203E+05
2094	6.700E+06	9.059E+02	4.949E+05
2095	6.700E+06	8.618E+02	4.708E+05
2096	6.700E+06	8.197E+02	4.478E+05
2097	6.700E+06	7.797E+02	4.260E+05
2098	6.700E+06	7.417E+02	4.052E+05
2099	6.700E+06	7.055E+02	3.854E+05
2100	6.700E+06	6.711E+02	3.666E+05
2101	6.700E+06	6.384E+02	3.488E+05
2102	6.700E+06	6.073E+02	3.317E+05
2103	6.700E+06	5.777E+02	3.156E+05
2104	6.700E+06	5.495E+02	3.002E+05
2105	6.700E+06	5.227E+02	2.855E+05
2106	6.700E+06	4.972E+02	2.716E+05
2107	6.700E+06	4.729E+02	2.584E+05
2108	6.700E+06	4.499E+02	2.458E+05
2109	6.700E+06	4.279E+02	2.338E+05
2110	6.700E+06	4.071E+02	2.224E+05
2111	6.700E+06	3.872E+02	2.115E+05
2112	6.700E+06	3.683E+02	2.012E+05
2113	6.700E+06	3.504E+02	1.914E+05
2114	6.700E+06	3.333E+02	1.821E+05
2115	6.700E+06	3.170E+02	1.732E+05
2116	6.700E+06	3.016E+02	1.647E+05
2117	6.700E+06	2.869E+02	1.567E+05
2118	6.700E+06	2.729E+02	1.491E+05
2119	6.700E+06	2.596E+02	1.418E+05
2120	6.700E+06	2.469E+02	1.349E+05
2121	6.700E+06	2.349E+02	1.283E+05
2122	6.700E+06	2.234E+02	1.220E+05
2123	6.700E+06	2.125E+02	1.161E+05
2124	6.700E+06	2.021E+02	1.104E+05
2125	6.700E+06	1.923E+02	1.050E+05

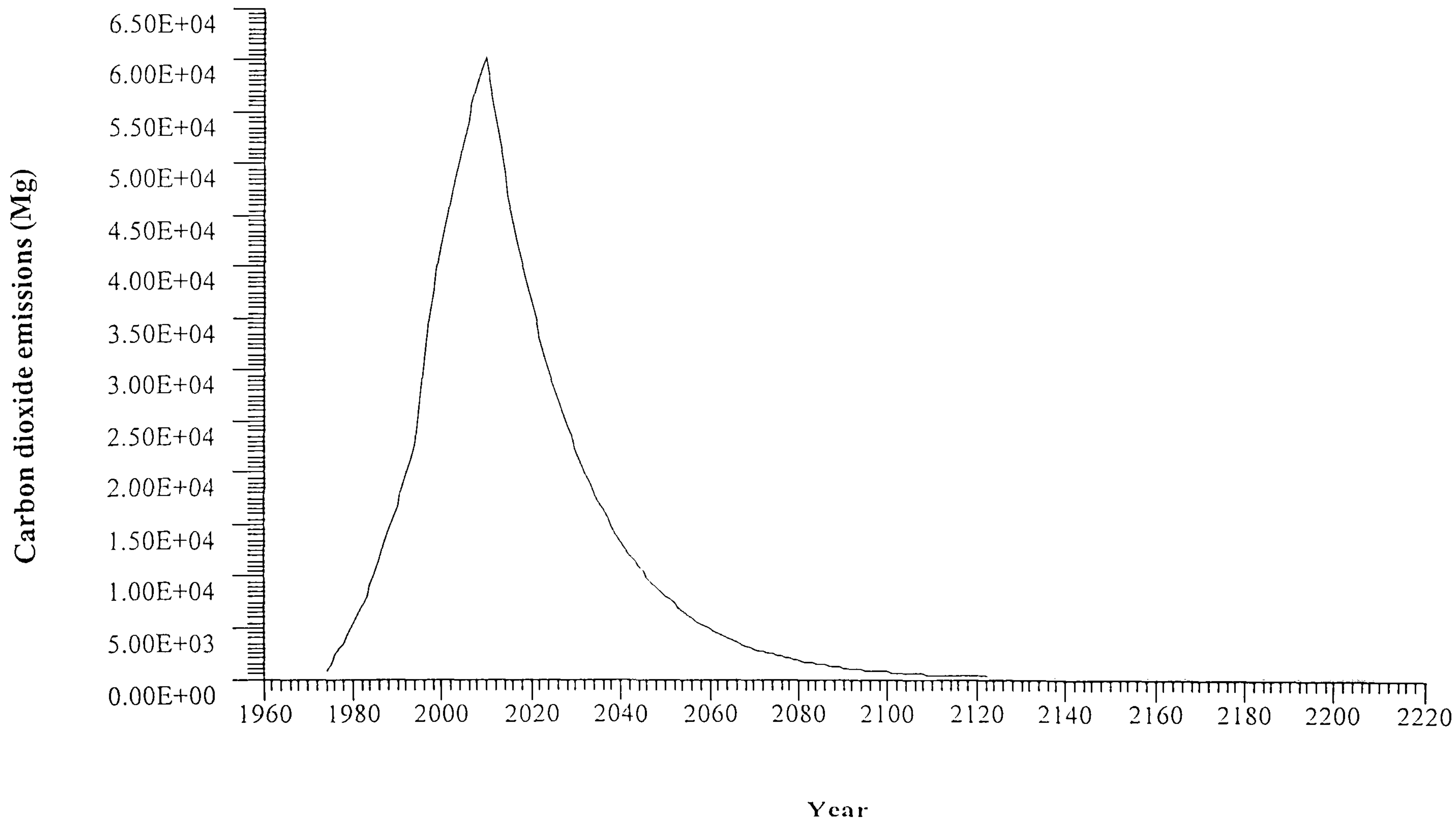
Carbon dioxide generation predictions for co-disposal wastes using CAA parameters for total area of [redacted] Landfill : waste input period 1973 - 2010

Year	Refuse In Place (Mg)	Carbon Dioxide Emission Rate (Mg/yr)	Carbon Dioxide Emission Rate (Cubic m/yr)
2126	6.700E+06	1.829E+02	9.992E+04
2127	6.700E+06	1.740E+02	9.505E+04
2128	6.700E+06	1.655E+02	9.041E+04
2129	6.700E+06	1.574E+02	8.600E+04
2130	6.700E+06	1.498E+02	8.181E+04
2131	6.700E+06	1.424E+02	7.782E+04
2132	6.700E+06	1.355E+02	7.402E+04
2133	6.700E+06	1.289E+02	7.041E+04
2134	6.700E+06	1.226E+02	6.698E+04
2135	6.700E+06	1.166E+02	6.371E+04
2136	6.700E+06	1.109E+02	6.061E+04
2137	6.700E+06	1.055E+02	5.765E+04
2138	6.700E+06	1.004E+02	5.484E+04
2139	6.700E+06	9.549E+01	5.216E+04
2140	6.700E+06	9.083E+01	4.962E+04
2141	6.700E+06	8.640E+01	4.720E+04
2142	6.700E+06	8.218E+01	4.490E+04
2143	6.700E+06	7.818E+01	4.271E+04
2144	6.700E+06	7.436E+01	4.062E+04
2145	6.700E+06	7.074E+01	3.864E+04
2146	6.700E+06	6.729E+01	3.676E+04
2147	6.700E+06	6.401E+01	3.497E+04
2148	6.700E+06	6.088E+01	3.326E+04
2149	6.700E+06	5.791E+01	3.164E+04
2150	6.700E+06	5.509E+01	3.010E+04
2151	6.700E+06	5.240E+01	2.863E+04
2152	6.700E+06	4.985E+01	2.723E+04
2153	6.700E+06	4.742E+01	2.590E+04
2154	6.700E+06	4.510E+01	2.464E+04
2155	6.700E+06	4.290E+01	2.344E+04
2156	6.700E+06	4.081E+01	2.230E+04
2157	6.700E+06	3.882E+01	2.121E+04
2158	6.700E+06	3.693E+01	2.017E+04
2159	6.700E+06	3.513E+01	1.919E+04
2160	6.700E+06	3.341E+01	1.825E+04
2161	6.700E+06	3.178E+01	1.736E+04
2162	6.700E+06	3.023E+01	1.652E+04
2163	6.700E+06	2.876E+01	1.571E+04
2164	6.700E+06	2.736E+01	1.495E+04
2165	6.700E+06	2.602E+01	1.422E+04
2166	6.700E+06	2.475E+01	1.352E+04
2167	6.700E+06	2.355E+01	1.286E+04

Carbon dioxide generation predictions for co-disposal wastes using CAA parameters for total area of [redacted] Landfill : waste input period 1973 - 2010

Year	Refuse In Place (Mg)	Carbon Dioxide Emission Rate (Mg/yr)	(Cubic m/yr)
2168	6.700E+06	2.240E+01	1.224E+04
2169	6.700E+06	2.131E+01	1.164E+04
2170	6.700E+06	2.027E+01	1.107E+04
2171	6.700E+06	1.928E+01	1.053E+04
2172	6.700E+06	1.834E+01	1.002E+04
2173	6.700E+06	1.744E+01	9.529E+03
2174	6.700E+06	1.659E+01	9.065E+03
2175	6.700E+06	1.578E+01	8.623E+03
2176	6.700E+06	1.501E+01	8.202E+03
2177	6.700E+06	1.428E+01	7.802E+03
2178	6.700E+06	1.359E+01	7.421E+03
2179	6.700E+06	1.292E+01	7.060E+03
2180	6.700E+06	1.229E+01	6.715E+03
2181	6.700E+06	1.169E+01	6.388E+03
2182	6.700E+06	1.112E+01	6.076E+03
2183	6.700E+06	1.058E+01	5.780E+03
2184	6.700E+06	1.006E+01	5.498E+03
2185	6.700E+06	9.573E+00	5.230E+03
2186	6.700E+06	9.106E+00	4.975E+03
2187	6.700E+06	8.662E+00	4.732E+03
2188	6.700E+06	8.240E+00	4.501E+03
2189	6.700E+06	7.838E+00	4.282E+03
2190	6.700E+06	7.456E+00	4.073E+03
2191	6.700E+06	7.092E+00	3.874E+03
2192	6.700E+06	6.746E+00	3.685E+03
2193	6.700E+06	6.417E+00	3.506E+03
2194	6.700E+06	6.104E+00	3.335E+03
2195	6.700E+06	5.806E+00	3.172E+03
2196	6.700E+06	5.523E+00	3.017E+03
2197	6.700E+06	5.254E+00	2.870E+03
2198	6.700E+06	4.998E+00	2.730E+03
2199	6.700E+06	4.754E+00	2.597E+03
2200	6.700E+06	4.522E+00	2.470E+03
2201	6.700E+06	4.302E+00	2.350E+03
2202	6.700E+06	4.092E+00	2.235E+03
2203	6.700E+06	3.892E+00	2.126E+03
2204	6.700E+06	3.702E+00	2.023E+03
2205	6.700E+06	3.522E+00	1.924E+03
2206	6.700E+06	3.350E+00	1.830E+03
2207	6.700E+06	3.187E+00	1.741E+03
2208	6.700E+06	3.031E+00	1.656E+03
2209	6.700E+06	2.883E+00	1.575E+03

Projected Carbon Dioxide Emissions for co-disposal wastes using CAA parameters for total area of landfill



APPENDIX G

Composite LFG Curves with Gas Management Guidance (adjusted for inerts)

LandGem Methane generation predictions (total LFG when adjusted for inerts) for domestic wastes using CAA parameters for southern, eastern (and total) areas of [redacted] Landfill: waste input period 1973 - 2000S/2000 - 2010E

Model Parameters

Lo :170.00 m^3 / Mg
k : 0.0500 1/yr
NMOC: 4000.00 ppmv
Methane : 50.0000 % volume
Carbon Dioxide : 50.0000 % volume

Landfill Parameters

Landfill type : No Co-Disposal
Year Opened : 1973 Current Year : 2000/2010 Closure Year: 2000/2010
Capacity : 6700000 Mg
Average Input Rate Required from current Year to Closure Year : 0.00 Mg/year

Model Results

Year	Generation S (Cubic m/yr)	Generation E (Cubic m/yr)	Generation Total (Cubic m/yr)
1974	4.25E+05		4.25E+05
1975	8.29E+05		8.29E+05
1976	1.21E+06		1.21E+06
1977	1.58E+06		1.58E+06
1978	1.93E+06		1.93E+06
1979	2.47E+06		2.47E+06
1980	2.99E+06		2.99E+06
1981	3.48E+06		3.48E+06
1982	3.95E+06		3.95E+06
1983	4.39E+06		4.39E+06
1984	5.03E+06		5.03E+06
1985	5.63E+06		5.63E+06
1986	6.42E+06		6.42E+06
1987	7.17E+06		7.17E+06
1988	7.88E+06		7.88E+06
1989	8.56E+06		8.56E+06
1990	9.21E+06		9.21E+06
1991	1.00E+07		1.00E+07
1992	1.08E+07		1.08E+07
1993	1.16E+07		1.16E+07
1994	1.25E+07		1.25E+07
1995	1.48E+07		1.48E+07
1996	1.71E+07		1.71E+07
1997	1.92E+07		1.92E+07
1998	2.05E+07		2.05E+07
1999	2.18E+07		2.18E+07
2000	2.20E+07	1.11E+06	2.31E+07
2001	2.09E+07	3.60E+06	2.45E+07

LandGem Methane generation predictions (total LFG when adjusted for inerts) for domestic wastes using CAA parameters for southern, eastern (and total) areas of [redacted] Landfill : waste input period 1973 - 2000S/2000 - 2010E

Year	Generation S (Cubic m/yr)	Generation E (Cubic m/yr)	Generation Total (Cubic m/yr)
2002	1.99E+07	5.98E+06	2.59E+07
2003	1.89E+07	8.23E+06	2.72E+07
2004	1.80E+07	1.04E+07	2.84E+07
2005	1.71E+07	1.24E+07	2.96E+07
2006	1.63E+07	1.44E+07	3.07E+07
2007	1.55E+07	1.62E+07	3.17E+07
2008	1.47E+07	1.80E+07	3.27E+07
2009	1.40E+07	1.95E+07	3.35E+07
2010	1.33E+07	1.93E+07	3.26E+07
2011	1.27E+07	1.84E+07	3.11E+07
2012	1.21E+07	1.75E+07	2.95E+07
2013	1.15E+07	1.66E+07	2.81E+07
2014	1.09E+07	1.58E+07	2.67E+07
2015	1.04E+07	1.50E+07	2.54E+07
2016	9.88E+06	1.43E+07	2.42E+07
2017	9.40E+06	1.36E+07	2.30E+07
2018	8.94E+06	1.29E+07	2.19E+07
2019	8.50E+06	1.23E+07	2.08E+07
2020	8.09E+06	1.17E+07	1.98E+07
2021	7.70E+06	1.11E+07	1.88E+07
2022	7.32E+06	1.06E+07	1.79E+07
2023	6.96E+06	1.01E+07	1.70E+07
2024	6.62E+06	9.58E+06	1.62E+07
2025	6.30E+06	9.12E+06	1.54E+07
2026	5.99E+06	8.67E+06	1.47E+07
2027	5.70E+06	8.25E+06	1.39E+07
2028	5.42E+06	7.85E+06	1.33E+07
2029	5.16E+06	7.46E+06	1.26E+07
2030	4.91E+06	7.10E+06	1.20E+07
2031	4.67E+06	6.75E+06	1.14E+07
2032	4.44E+06	6.42E+06	1.09E+07
2033	4.22E+06	6.11E+06	1.03E+07
2034	4.02E+06	5.81E+06	9.83E+06
2035	3.82E+06	5.53E+06	9.35E+06
2036	3.64E+06	5.26E+06	8.89E+06
2037	3.46E+06	5.00E+06	8.46E+06
2038	3.29E+06	4.76E+06	8.05E+06
2039	3.13E+06	4.53E+06	7.66E+06
2040	2.98E+06	4.31E+06	7.28E+06
2041	2.83E+06	4.10E+06	6.93E+06
2042	2.69E+06	3.90E+06	6.59E+06
2043	2.56E+06	3.71E+06	6.27E+06
2044	2.44E+06	3.53E+06	5.96E+06
2045	2.32E+06	3.35E+06	5.67E+06

LandGem Methane generation predictions (total LFG when adjusted for inerts) for domestic wastes using CAA parameters for southern, eastern (and total) areas of [redacted] Landfill: waste input period 1973 - 2000S/2000 - 2010E

Year	Generation S (Cubic m/yr)	Generation E (Cubic m/yr)	Generation Total (Cubic m/yr)
2046	2.21E+06	3.19E+06	5.40E+06
2047	2.10E+06	3.03E+06	5.13E+06
2048	2.00E+06	2.89E+06	4.88E+06
2049	1.90E+06	2.75E+06	4.64E+06
2050	1.81E+06	2.61E+06	4.42E+06
2051	1.72E+06	2.48E+06	4.20E+06
2052	1.63E+06	2.36E+06	4.00E+06
2053	1.55E+06	2.25E+06	3.80E+06
2054	1.48E+06	2.14E+06	3.62E+06
2055	1.41E+06	2.03E+06	3.44E+06
2056	1.34E+06	1.94E+06	3.27E+06
2057	1.27E+06	1.84E+06	3.11E+06
2058	1.21E+06	1.75E+06	2.96E+06
2059	1.15E+06	1.67E+06	2.82E+06
2060	1.10E+06	1.58E+06	2.68E+06
2061	1.04E+06	1.51E+06	2.55E+06
2062	9.91E+05	1.43E+06	2.42E+06
2063	9.42E+05	1.36E+06	2.31E+06
2064	8.96E+05	1.30E+06	2.19E+06
2065	8.53E+05	1.23E+06	2.09E+06
2066	8.11E+05	1.17E+06	1.98E+06
2067	7.72E+05	1.12E+06	1.89E+06
2068	7.34E+05	1.06E+06	1.80E+06
2069	6.98E+05	1.01E+06	1.71E+06
2070	6.64E+05	9.61E+05	1.62E+06
2071	6.32E+05	9.14E+05	1.55E+06
2072	6.01E+05	8.69E+05	1.47E+06
2073	5.72E+05	8.27E+05	1.40E+06
2074	5.44E+05	7.87E+05	1.33E+06
2075	5.17E+05	7.48E+05	1.27E+06
2076	4.92E+05	7.12E+05	1.20E+06
2077	4.68E+05	6.77E+05	1.14E+06
2078	4.45E+05	6.44E+05	1.09E+06
2079	4.23E+05	6.13E+05	1.04E+06
2080	4.03E+05	5.83E+05	9.85E+05
2081	3.83E+05	5.54E+05	9.37E+05
2082	3.64E+05	5.27E+05	8.92E+05
2083	3.47E+05	5.02E+05	8.48E+05
2084	3.30E+05	4.77E+05	8.07E+05
2085	3.14E+05	4.54E+05	7.68E+05
2086	2.98E+05	4.32E+05	7.30E+05
2087	2.84E+05	4.11E+05	6.94E+05
2088	2.70E+05	3.91E+05	6.61E+05
2089	2.57E+05	3.72E+05	6.28E+05

LandGem Methane generation predictions (total LFG when adjusted for inerts) for domestic wastes using CAA parameters for southern, eastern (and total) areas of [redacted] Landfill waste input period 1973 - 2000S/2000 - 2010E

Year	Generation S (Cubic m/yr)	Generation E (Cubic m/yr)	Generation Total (Cubic m/yr)
2090	2.44E+05	3.53E+05	5.98E+05
2091	2.32E+05	3.36E+05	5.69E+05
2092	2.21E+05	3.20E+05	5.41E+05
2093	2.10E+05	3.04E+05	5.15E+05
2094	2.00E+05	2.89E+05	4.89E+05
2095	1.90E+05	2.75E+05	4.65E+05
2096	1.81E+05	2.62E+05	4.43E+05
2097	1.72E+05	2.49E+05	4.21E+05
2098	1.64E+05	2.37E+05	4.01E+05
2099	1.56E+05	2.25E+05	3.81E+05
2100	1.48E+05	2.14E+05	3.63E+05
2101	1.41E+05	2.04E+05	3.45E+05
2102	1.34E+05	1.94E+05	3.28E+05
2103	1.28E+05	1.85E+05	3.12E+05
2104	1.21E+05	1.76E+05	2.97E+05
2105	1.15E+05	1.67E+05	2.82E+05
2106	1.10E+05	1.59E+05	2.69E+05
2107	1.04E+05	1.51E+05	2.56E+05
2108	9.93E+04	1.44E+05	2.43E+05
2109	9.45E+04	1.37E+05	2.31E+05
2110	8.99E+04	1.30E+05	2.20E+05
2111	8.55E+04	1.24E+05	2.09E+05
2112	8.13E+04	1.18E+05	1.99E+05
2113	7.74E+04	1.12E+05	1.89E+05
2114	7.36E+04	1.06E+05	1.80E+05
2115	7.00E+04	1.01E+05	1.71E+05
2116	6.66E+04	9.63E+04	1.63E+05
2117	6.33E+04	9.16E+04	1.55E+05
2118	6.02E+04	8.72E+04	1.47E+05
2119	5.73E+04	8.29E+04	1.40E+05
2120	5.45E+04	7.89E+04	1.33E+05
2121	5.19E+04	7.50E+04	1.27E+05
2122	4.93E+04	7.14E+04	1.21E+05
2123	4.69E+04	6.79E+04	1.15E+05
2124	4.46E+04	6.46E+04	1.09E+05
2125	4.25E+04	6.14E+04	1.04E+05
2126	4.04E+04	5.84E+04	9.88E+04
2127	3.84E+04	5.56E+04	9.40E+04
2128	3.65E+04	5.29E+04	8.94E+04
2129	3.48E+04	5.03E+04	8.50E+04
2130	3.31E+04	4.78E+04	8.09E+04
2131	3.15E+04	4.55E+04	7.70E+04
2132	2.99E+04	4.33E+04	7.32E+04
2133	2.85E+04	4.12E+04	6.96E+04

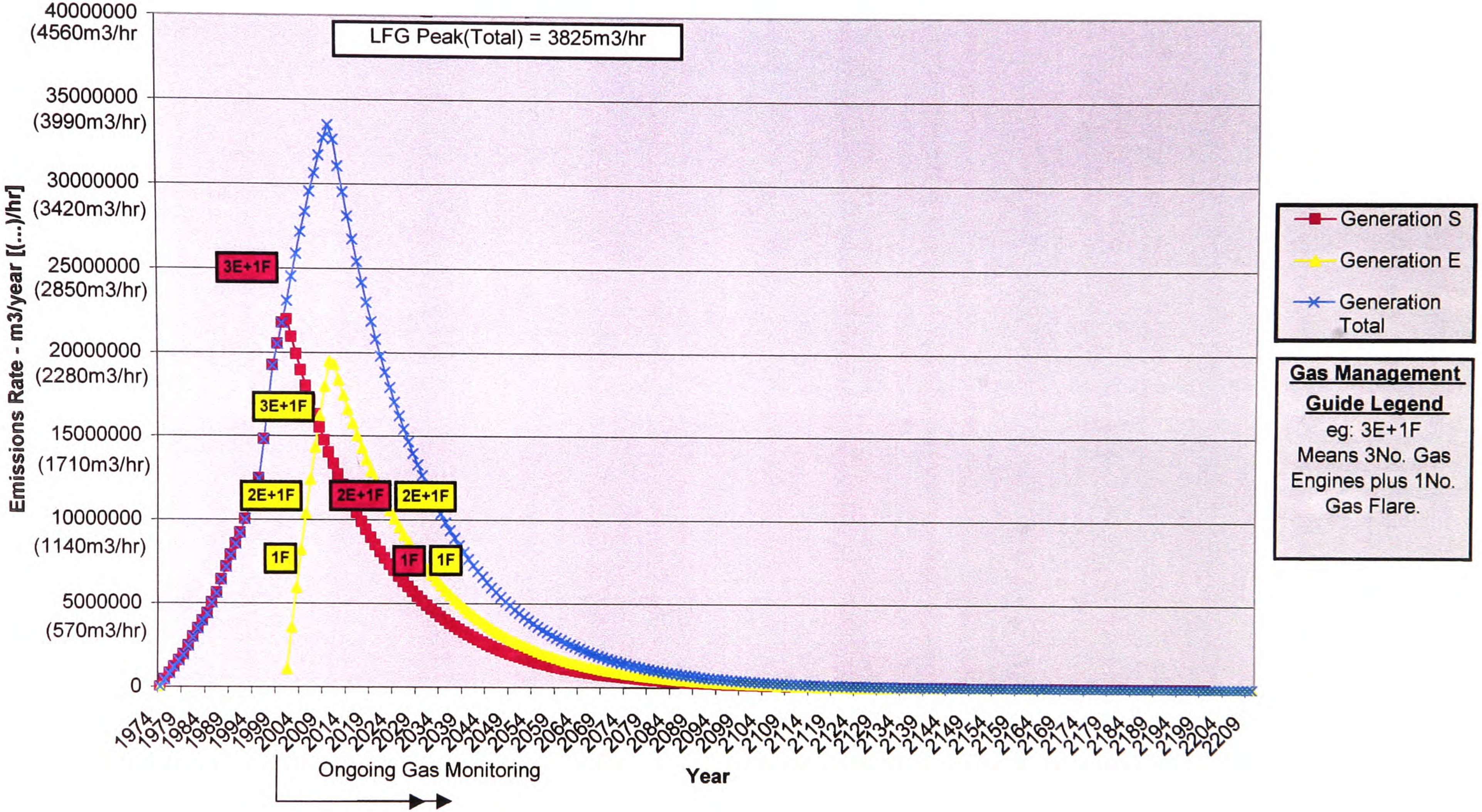
LandGem Methane generation predictions (total LFG when adjusted for inerts) for domestic wastes using CAA parameters for southern, eastern (and total) areas of [redacted] Landfill : waste input period 1973 - 2000S/2000 - 2010E

Year	Generation S (Cubic m/yr)	Generation E (Cubic m/yr)	Generation Total (Cubic m/yr)
2134	2.71E+04	3.92E+04	6.62E+04
2135	2.58E+04	3.73E+04	6.30E+04
2136	2.45E+04	3.54E+04	5.99E+04
2137	2.33E+04	3.37E+04	5.70E+04
2138	2.22E+04	3.21E+04	5.42E+04
2139	2.11E+04	3.05E+04	5.16E+04
2140	2.01E+04	2.90E+04	4.91E+04
2141	1.91E+04	2.76E+04	4.67E+04
2142	1.81E+04	2.63E+04	4.44E+04
2143	1.73E+04	2.50E+04	4.22E+04
2144	1.64E+04	2.38E+04	4.02E+04
2145	1.56E+04	2.26E+04	3.82E+04
2146	1.49E+04	2.15E+04	3.63E+04
2147	1.41E+04	2.04E+04	3.46E+04
2148	1.34E+04	1.95E+04	3.29E+04
2149	1.28E+04	1.85E+04	3.13E+04
2150	1.22E+04	1.76E+04	2.98E+04
2151	1.16E+04	1.67E+04	2.83E+04
2152	1.10E+04	1.59E+04	2.69E+04
2153	1.05E+04	1.51E+04	2.56E+04
2154	9.96E+03	1.44E+04	2.44E+04
2155	9.47E+03	1.37E+04	2.32E+04
2156	9.01E+03	1.30E+04	2.21E+04
2157	8.57E+03	1.24E+04	2.10E+04
2158	8.15E+03	1.18E+04	1.99E+04
2159	7.76E+03	1.12E+04	1.90E+04
2160	7.38E+03	1.07E+04	1.80E+04
2161	7.02E+03	1.02E+04	1.72E+04
2162	6.68E+03	9.66E+03	1.63E+04
2163	6.35E+03	9.19E+03	1.55E+04
2164	6.04E+03	8.74E+03	1.48E+04
2165	5.75E+03	8.31E+03	1.41E+04
2166	5.47E+03	7.91E+03	1.34E+04
2167	5.20E+03	7.52E+03	1.27E+04
2168	4.95E+03	7.15E+03	1.21E+04
2169	4.70E+03	6.81E+03	1.15E+04
2170	4.47E+03	6.47E+03	1.09E+04
2171	4.26E+03	6.16E+03	1.04E+04
2172	4.05E+03	5.86E+03	9.91E+03
2173	3.85E+03	5.57E+03	9.42E+03
2174	3.66E+03	5.30E+03	8.96E+03
2175	3.48E+03	5.04E+03	8.53E+03
2176	3.32E+03	4.80E+03	8.11E+03
2177	3.15E+03	4.56E+03	7.72E+03

LandGem Methane generation predictions (total LFG when adjusted for inerts) for domestic wastes using CAA parameters for southern, eastern (and total) areas of [redacted] Landfill : waste input period 1973 - 2000S/2000 - 2010E

Year	Generation S (Cubic m/yr)	Generation E (Cubic m/yr)	Generation Total (Cubic m/yr)
2178	3.00E+03	4.34E+03	7.34E+03
2179	2.85E+03	4.13E+03	6.98E+03
2180	2.71E+03	3.93E+03	6.64E+03
2181	2.58E+03	3.74E+03	6.32E+03
2182	2.46E+03	3.55E+03	6.01E+03
2183	2.34E+03	3.38E+03	5.72E+03
2184	2.22E+03	3.21E+03	5.44E+03
2185	2.11E+03	3.06E+03	5.17E+03
2186	2.01E+03	2.91E+03	4.92E+03
2187	1.91E+03	2.77E+03	4.68E+03
2188	1.82E+03	2.63E+03	4.45E+03
2189	1.73E+03	2.50E+03	4.23E+03
2190	1.65E+03	2.38E+03	4.03E+03
2191	1.57E+03	2.27E+03	3.83E+03
2192	1.49E+03	2.16E+03	3.64E+03
2193	1.42E+03	2.05E+03	3.47E+03
2194	1.35E+03	1.95E+03	3.30E+03
2195	1.28E+03	1.86E+03	3.14E+03
2196	1.22E+03	1.76E+03	2.98E+03
2197	1.16E+03	1.68E+03	2.84E+03
2198	1.10E+03	1.60E+03	2.70E+03
2199	1.05E+03	1.52E+03	2.57E+03
2200		1.44E+03	1.44E+03
2201		1.37E+03	1.37E+03
2202		1.31E+03	1.31E+03
2203		1.24E+03	1.24E+03
2204		1.18E+03	1.18E+03
2205		1.13E+03	1.13E+03
2206		1.07E+03	1.07E+03
2207		1.02E+03	1.02E+03
2208		9.68E+02	9.68E+02
2209		9.21E+02	9.21E+02

Gas Generation Curves - Total LFG Prediction



APPENDIX 2

Example of Landfill Leachate Water Balance Computation

AUTHORITY ********
ENVIRONMENTAL PROTECTION DEPARTMENT

******** *******

EXTENSION

OPERATIONAL WATER BALANCE REVIEW

MARCH 1999

Prepared for:
Authority ********

Prepared by:
PB Kennedy & Donkin Limited
29 Cathedral Road
Cardiff
CF1 9HA

AUTHORITY ********

Report Title	:	******** ******* Extension Operational Water Balance Review
Report Status	:	Consultation Release: Version 1
Date of Issue	:	March 1999
Job No.	:	BECCF***.***
Prepared by	:	.... (G Jones)
Checked by	:	.... (K C Davies)
Check Cat.	:	B
Approved by	:	.... (A Dolecki)

CONTENTS

1 INTRODUCTION

1.1 This report has been prepared by PB Kennedy and Donkin Limited on behalf of the Highways and Transportation/Environmental Protection Department, Authority ********. Application has been made by Authority ******** for a waste management licence to allow the 'contained' eastward extension of the existing un-contained southern landfilling operations at ********. Extended land filling will proceed eastward beyond the recently installed multi-component separation barrier. A site location plan is presented as Figure No. 1 *(Diagrammatic Representation Included).*

1.2 As part of the application, the Environment Agency has requested a review of potential leachate volume generation for the eastern extension. The terms of reference for this work were presented in PB Kennedy & Donkin's proposal letter to Walters UK Limited dated ******, copied to Authority ********.

1.3 This report details the scope of work undertaken by PB Kennedy & Donkin, the data provided by Authority ********, the method of calculation used to assess leachate generation volumes, comment on the waste parameters selected for calculation and presentation of results within a sensitivity envelope.

2 SCOPE OF REVIEW

2.1 The scope of work relating to the water balance review is detailed below and remains largely unchanged from the details contained in PB Kennedy & Donkin's original proposal letter:

- Inspect water balance calculations carried out by other consultants.
- Liaise with Authority ******** regarding waste type, waste input volume estimates, typical waste densities and absorptive capacities.
- Rainfall data relevant to the site.
- Develop and set up the water balance spreadsheet model following the guidelines set out in Waste Management Paper (WMP) 26B.
- Conduct validation runs of the water balance spreadsheet model as a check against the WMP 26B worked example.
- Carry out preliminary runs of the **** Extension model using initial parameter estimates.
- Liaise with Authority ******** regarding planned adjustments to landfill phasing and programming.
- Build in refinements to the spreadsheet model utilising more precise phasing and area information relating to the **** Extension.
- Provide estimates of maximum and cumulative leachate volumes and anticipated maximum leachate discharge rates.
- Make comparisons with previous approach and estimates.
- Conduct a series of sensitivity analyses involving parameter adjustment.
- Present all findings to Authority ********.
- Discuss with Authority ******** the adequacy of proposed leachate handling arrangements in light of the findings of the water balance calculations.

- If necessary, suggest improvements to Authority ******** on phasing, restoration timing, intermediate capping etc. to control rainfall infiltration effects.

3 SPREADSHEET MODEL

3.1 Methodology and Validation

3.1.1 Water Balance Calculations were carried out for the Eastern Extension following guidelines laid down in Waste Management Paper 26B (WMP 26B). A Water Balance Spreadsheet was constructed using the WMP 26B input criteria and validated against the published worked example, prior to undertaking specific calculations for the ***** Extension.

3.1.2 The WMP 26B methodology which considers active tipping, intermediate capping and restored areas of a landfill, differs from the approach adopted previously by ****** Partnership (***) which calculated leachate generation for a discrete working cell only.

3.2 Phasing And Sequencing

3.2.1 Following discussions and meetings with Authority ********, information on waste input volumes, typical waste type and comprehensive phasing/ sequencing details were obtained. This enabled the basic "East Extension Spreadsheet Model" to be constructed and developed. Following model development calculations were then undertaken on a four zone sequencing logic comprising – Area 1 (North), Area 2 (South), Area 3 (Central East) and Area 4 (Central West). Sequencing is represented diagrammatically in Figure No. 2.

3.2.2 Area values listed in the spreadsheet computations for each phase of landfilling within the eastern extension were determined using AutoCad digital plans. The western edge of the eastern extension is defined by the crest of the separation barrier. Wastes lying to the west of the separation barrier have been taken as contributing to leachate production in the older un-contained areas of tipping. To reflect operational development the eastern extension area values were further classified to represent changes in active, intermediate capping and restoration zones over the anticipated life of the landfill extension, in line with programme details provided by Authority ******** and shown in figure 3.

4 REFERENCE MATERIAL/PARAMETER SOURCES

4.1 Rainfall Data

4.1.1 Rainfall figures for the local area were provided by Authority ********. The data-set comprised monthly rainfall figures and all monthly averages for the years 1992/1993 to 1998. Based on various case studies, monthly *effective rainfall* figures were derived as a percentage of total rainfall to allow for and to show the effect of evapotranspiration effects throughout a typical year, following a methodology published in the DoE Report No. CWM 031/91, 'A Review of Water Balance Methods and their Application to Landfill in the UK'. A summary table of rainfall figures, monthly rainfall averages and values used to represent effective rainfall are shown below in Table No. 1.

Month/Year	1992/93	1993/94	1994/95	1995/96	1996/97	1997/98	Month Average (mm)	E.R. (mm)
January	173.9	174.1	211.0	73.4	23.1	144.9	133.4	123.3
February	14.6	140.3	138.7	104.6	196.7	22.0	102.8	87.6
March	86.4	148.3	52.2	66.1	32.6	178.9	94.1	62.0
April	65.0	86.4	77.5	27.9	71.4	34.0	69.1	40.1
May	49.0	60.9	87.2	86.2	99.7	97.9	75.2	0.0
June	19.7	68.0	45.8	8.9	18.7	80.3	56.4	0.0
July	90.3	135.7	42.8	44.2	49.1	88.5	73.9	0.0
August	184.5	68.0	62.0	9.2	173.6	266.3	117.7	28.6
September	109.9	95.3	87.8	122.4	53.5	73.3	94.4	12.8
October	60.0	82.2	139.7	108.4	182.0	84.9	132.2	96.3
November	220.0	94.9	146.0	117.1	156.2	159.0	144.6	135.7
December	71.6	242.6	199.7	124.7	51.5	123.0	134.8	125.3
Totals (mm)	1144.9	1396.7	1290.4	893.1	1108.1	1353.0	1228.6	711.7

(Table No. 1)

4.2 Waste Parameters

4.2.1 Waste Input Rate: An annual waste input rate of 300,000 t/year (placed in 2 m high lifts) has been advised by Authority ********. For the purposes of this review the input tipping rate has been maintained at a constant value. It is anticipated, however, that during the life of the extension, waste minimisation, re-cycling and waste transformation initiatives may lead to a general reduction in the annual volume of landfilled tipping residues.

4.2.2 Waste Density: A waste density value of 1 t/m^3 has been advised by Authority ******** and this value has been used as a constant in our calculations. This value lies in the range quoted in WMP 26B for bio-reactive wastes.

4.2.3 Waste Absorption Capacity: Typical values listed in a review of waste absorptive capacities range from 0.05 m^3/m^3 to 0.35 m^3/m^3 as cited in the DoE Report No. CWM031/91, 'A Review of Water Balance Methods and their Application to Landfill in the UK'. However, to avoid underestimating leachate volumes, and to provide an anticipated 'worst case' scenario an initial estimate of 0.01 m^3/m^3 was selected. The effect of changes to this parameter was further "tested" as part of a sensitivity analysis.

4.2.4 Cap Percolation: From Dutch standards a rainfall infiltration value of 20 mm per annum is commonly cited for landfill cap performance. This value has been adopted for the 'worst case' calculation.

5 SENSITIVITY ANALYSIS

5.1 Parameter Adjustments

5.1.1 The 'benchmark' calculation (Run No. 1) was conducted using an initial set of critical parameters. These are detailed below and represent a 'worst case' or maximum for leachate production.

- Waste absorption capacity $0.01m^3/m^3$
- Active area rainfall infiltration 100% of total rainfall
- Intermediate cap rainfall infiltration 50% of total rainfall
- Restored cap rainfall infiltration 20 mm/annum

5.1.2 As part of a sensitivity analysis a series of water balance calculations using adjusted parameters were then simulated to assess potential variations in the following:

- Monthly leachate production. (m^3) – using total rainfall.
- Monthly maximum and minimum rates of leachate production. (Litres/second) - using total rainfall.
- Cumulative total leachate volumes throughout the life of the landfilling operation. (m^3) – using both total rainfall and effective rainfall.

5.1.3 Total rainfall solely, has been used for the monthly leachate volume and discharge calculations to confirm correct sizing of the leachate carrier system for peak flow conditions.

5.2 Sensitivity Results

5.2.1 In total, seven runs of the monthly water balance calculation were undertaken incorporating gradual modifications to the critical parameters. The modifications primarily consisted of increases to waste absorption capacity, reduction in rainfall infiltration to intermediate capped areas and reduction to rainfall infiltration to restored landfill areas. The latter follows recent contract research work undertaken for U.K. DoE - 'Infiltration Study - An Assessment of Infiltration Rates Through Multi-layered Landfill Cover Systems', (May 1996) for soil covers incorporating a geosynthetic drainage layer. Infiltration rates for the soil cover trial panels tested were reported in the range as low as 1 - 10 mm/annum. At ******** capping and restoration has typically included a composite geosynthetic capping system incorporating geotextile cushion, HDPE geomembrane, plus geocomposite drainage layer - more sophisticated than the cover system researched under the DoE Contract.

Reduction to 5 mm/annum for permanently capped areas is thus considered justified for the purpose of the sensitivity analysis.

5.2.2 The results of all seven water balance calculations are tabulated below (Table No. 2):

Run No.	Absorption Capacity	Inter. Infil. Multiplier	Capped Infiltration Infil. Mm/a	Min. Leachate Volume m^3/month	Max. Leachate Volume m^3/month	Min. Discharge Litres/sec.	Max. Discharge Litres/sec.
1	0.01	0.50	20.00	218.34	18474.53	0.08	7.23
2	0.02	0.45	17.50	191.04	18474.35	0.07	7.13
3	0.03	0.40	15.00	163.75	18203.18	0.06	7.02
4	0.04	0.35	12.50	136.46	17932.00	0.05	6.92
5	0.05	0.30	10.00	109.17	17660.82	0.04	6.81
6	0.06	0.25	7.50	81.88	17389.64	0.03	6.71
7	0.07	0.20	5.00	54.58	17118.47	0.02	6.60

(Table No. 2)

5.2.3 Sensitivity envelopes showing the maximum and minimum estimates of monthly leachate production and discharge rates are presented in Figure No. 4.

6 CONCLUSIONS

6.1 Monthly and Cumulative Leachate Volumes

6.1.1 With reference to the result table of sensitivity analyses (Table No. 2), and to the polynomial 'best fit' trendlines (Figure No. 4), an expected decline in leachate volumes is confirmed to occur as a result of reductions in rainfall infiltration values, increases in waste absorption values etc. The general reductions can be tracked through the sensitivity analysis and are particularly noticeable between months 40 and 80. This period generally corresponds with the commencement of 'first pass' active operations in Area 3 (Central East) and Area 4 (Central West) as well as the re-commencement of tipping operations in these same areas during 'second pass' operations. At these times the Area 1 and Area 2 zones are experiencing intermediate capping limiting direct rainfall percolation. From Figure No. 4, maximum monthly leachate generation for the 'worst case' scenario is predicted at 18,746 m^3 in month 95 with maximum leachate generation for the 'best case' scenario predicted at 17,118 m^3 in month 95 – a difference of only 1,628 m^3. During month 95, the majority of contributing areas are active with the highest monthly rainfall of the year coincident at this time. The influence of modifications to absorption capacity during month 95 under these conditions, would be negligible with the waste capable of suppressing a relatively small proportion of available inflow. This would serve to explain the small leachate volume difference seen between the 'best' and 'worst' case scenarios at month 95.

6.1.2 Cumulative leachate production volumes have also been derived for both total and effective rainfall conditions under the 'worst' case (Run No. 1) and details are shown in Figure No. 5. For total rainfall, the maximum cumulative leachate production at the end of tipping is 1,225,921 m^3 using Run No. 1 but with effective rainfall a reduced cumulative leachate production volume of 703,230 m^3 is predicted at the end of tipping. These figures offer guidance with respect to budget predictions for leachate treatment for the phasing logic adopted in this study.

6.2 Adequacy of Leachate Carrier Drain

6.2.1 The leachate carrier installed at the western toe of the east containment bund is of plastic smooth internal wall construction, internal bore 450 mm and laid to a general fall of 1 in 2,235. From the hydraulic tables for pipelines the discharge capacity of this pipeline under free outfall conditions is 59 l/s. (K_s (mm) = 1.5 – Value for slimed sewers – tables for the hydraulic design of pipes, sewers and channels 6th ed. Hydraulic Research Wallingford). Taking the maximum monthly leachate estimate of 18,746 m^3 this converts to a rate of generation of 7.23 l/s over the month – well within the capacity of the leachate carrier drain. Even accounting for tide locked periods if free outfall condition periods are halved the required rate of discharge is 14.46 l/s to clear the leachate production through the month – again well within the capacity of the leachate drain. Condition of the leachate carrier pipe should be routinely checked using CCTV techniques with the pipeline routinely flushed/jetted to avoid biofouling.

6.3 Closing Statement

6.3.1 The results of worst case and sensitivity adjustments calculations relating to estimated leachate production for the ******** ***** Extension show the predicted flow rates to be within the capacity of the leachate carrier pipe proposed. Actual flow rates can be monitored during the filling operations at the site for the purpose of comparison with the calculated predictions.

6.3.2 A digital spreadsheet model will be made available to Authority ******** to enable adjustments to sequencing/phasing to be modelled together with any operational adjustments such as changes in waste input rates, intermediate capping provision, surface water management and the timetable for final restoration etc.

6.3.3 Leachate and surface water collection and discharge arrangements will need to be subject to continued review throughout the operational phases of landfilling. The aim will be to ensure that leachate production is controlled and effectively managed. With Authority ********'s use of the digital spreadsheet model PB Kennedy & Donkin will continue to liaise with Authority ******** on leachate volumes produced and the options for minimisation, if needed, including surface water management matters, intermediate capping and final restoration coverage and programming etc.

6.3.4 As stated in 6.2.1, the leachate carrier pipe should be routinely inspected as part of a regular maintenance programme.

7 REFERENCES

LANDVA, A O and Clark, J I. 1990. Geotechnics of Waste Fill, in Geotechnics of Waste Fills, Theory and Practice. (eds. Landra and Knowles). ASTM STP 1070.

OWENS, I S. 1993. Geotechnical Practice for Waste Disposal (ed. David E Daniel). Published by Chapman and Hall

DEPARTMENT OF THE ENVIRONMENT. Wastes Technical Division Research Report No. CWM 031/91A. Review of Water Balance Methods and their Application to Landfill in the U.K.

DEPARTMENT OF THE ENVIRONMENT. 1994. Waste Management Paper No. 26F; Landfill Co-disposal. A Draft for Consultation. London: HMSO.

DEPARTMENT OF THE ENVIRONMENT. 1995. Waste Management Paper 26B; Landfill Design, Construction and Operational Practice London: HMSO

DEPARTMENT OF THE ENVIRONMENT. 1994. Waste Management Paper No. 4. Licensing of Waste Management Facilities, London: HMSO

****** ****** *******. 1993. ******** Landfill Proposed ***** ********. Report on Water Balance Document Reference: ******

HYDRAULIC RESEARCH, WALLINGFORD. Tables for the Hydraulic Design of Pipes, Sewers and Channels 6th Edition.

FIGURES

DETAILS LEFT BLANK

APPENDIX 2 - FIGURE 1: SITE LOCATION
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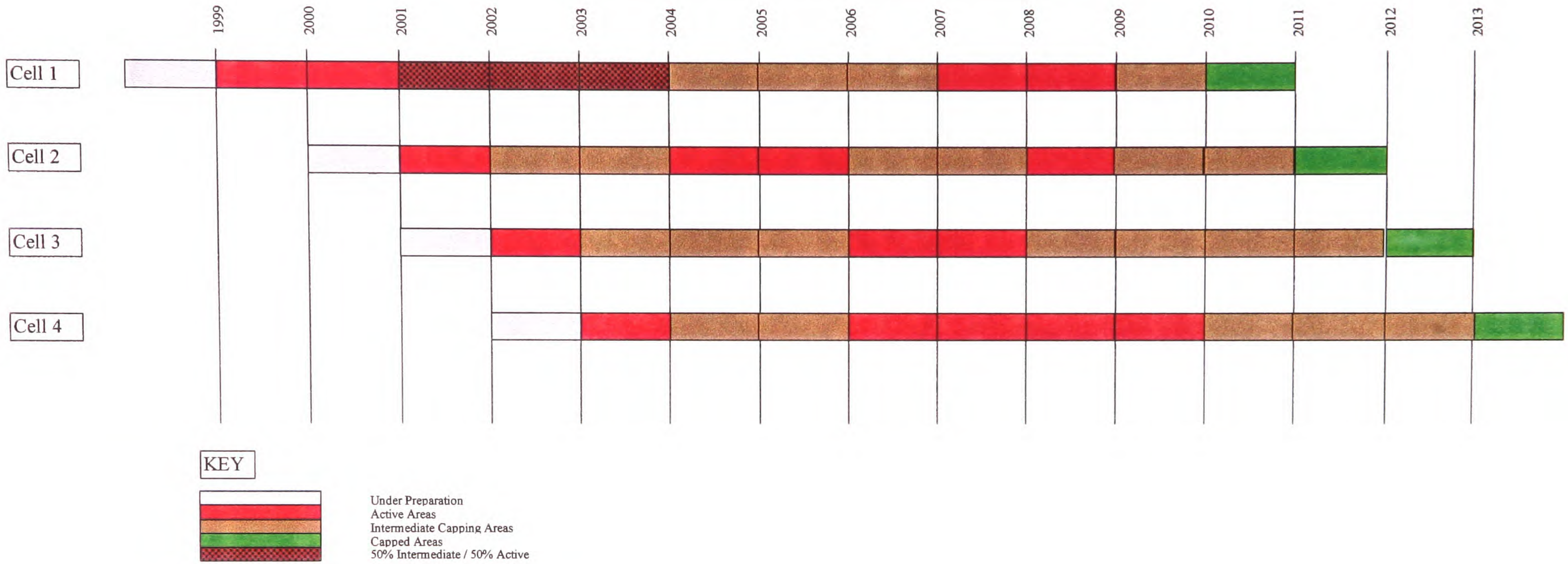
***** *** ******* Extension - Filling / Sequencing Plan



REV	DATE		BY	CHKD	NOTES
A	03/99	General revision description Cell 1 amended between 2001 and 2003 from active conditions only to intermediate/active conditions.			General notes to go in this box

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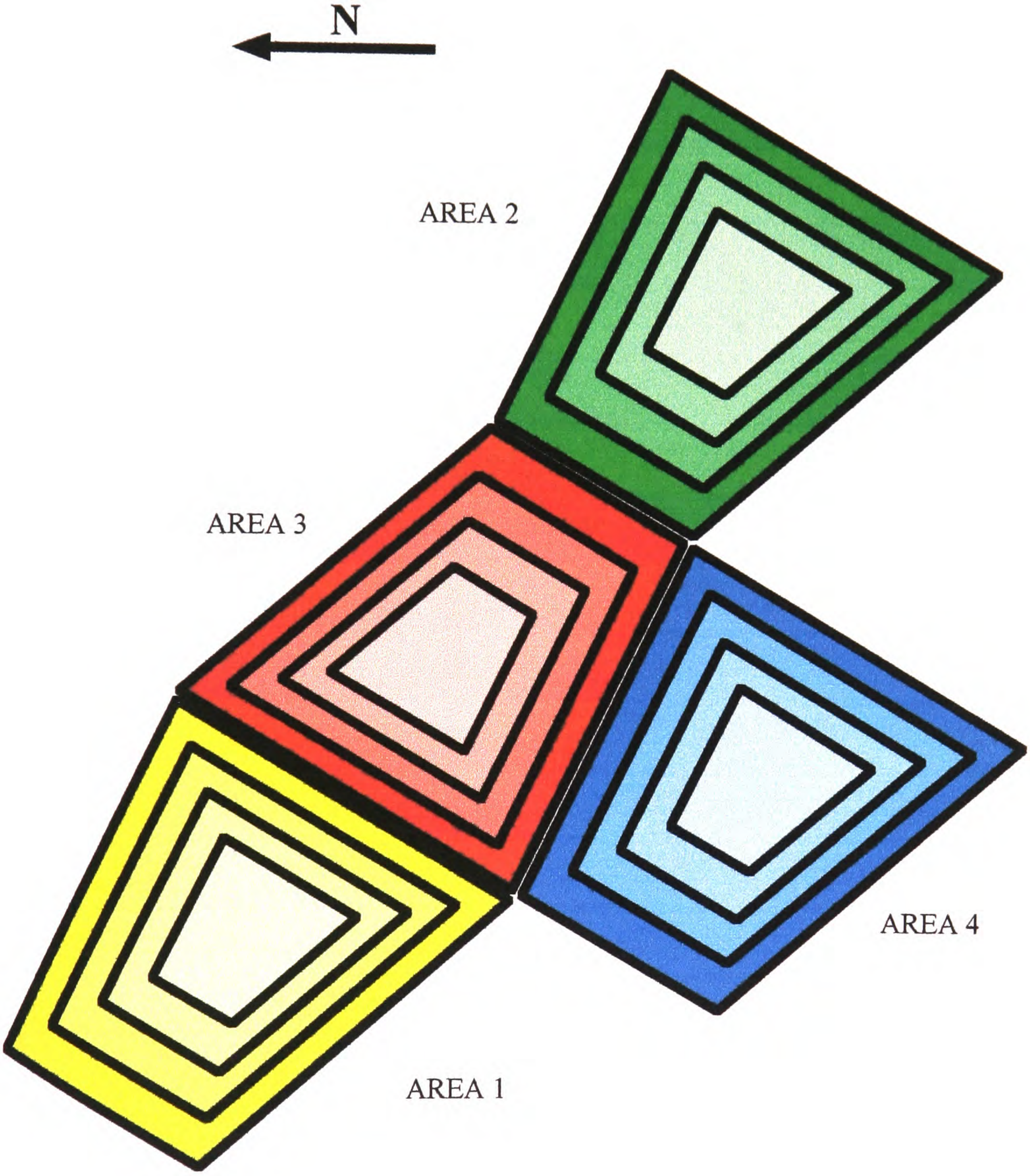
******* ****** COUNCIL
ENVIROMENTAL PROTECTION DEPT.
***** *** ******* EXTENSION

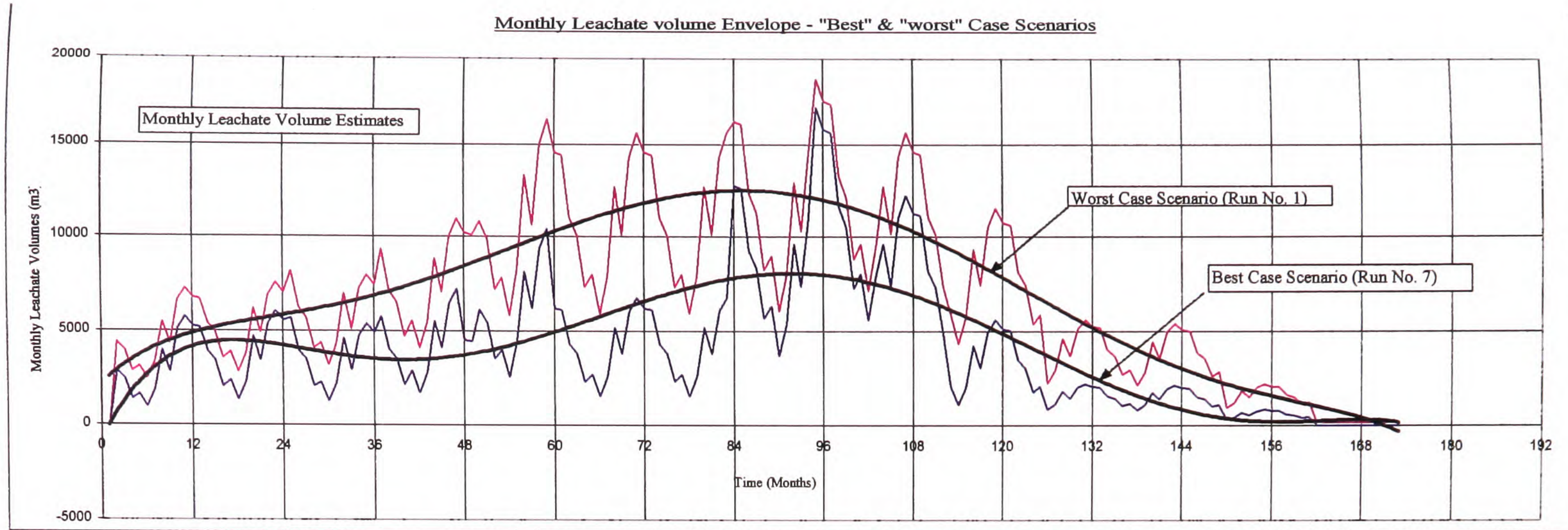
TITLE
***** *** ********* EXTENSION - FILLING / SEQUENCING PLAN

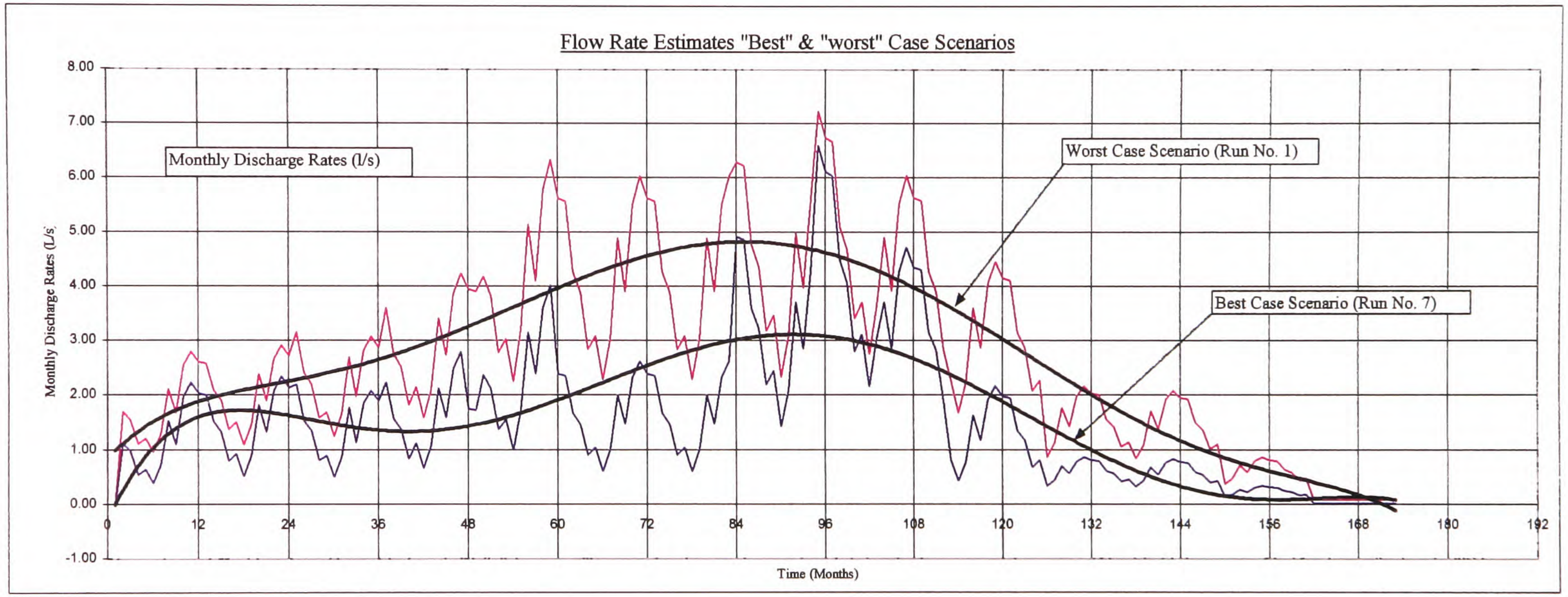
DATE	MAR '99	PRODUCED BY	GJ
SCALE	NTS	CHECKED	KD
REF		APPROVED	KD

DRAWING NUMBER
BECCF***/FIG 2(a)



APPENDIX 2 - FIGURE 3: LANDFILL SHEMATIC SHOWING VARYING UPFILLAREAS USED IN WATER BALANCE COMPUTATION





REV	DATE	BY	CHKD	NOTES

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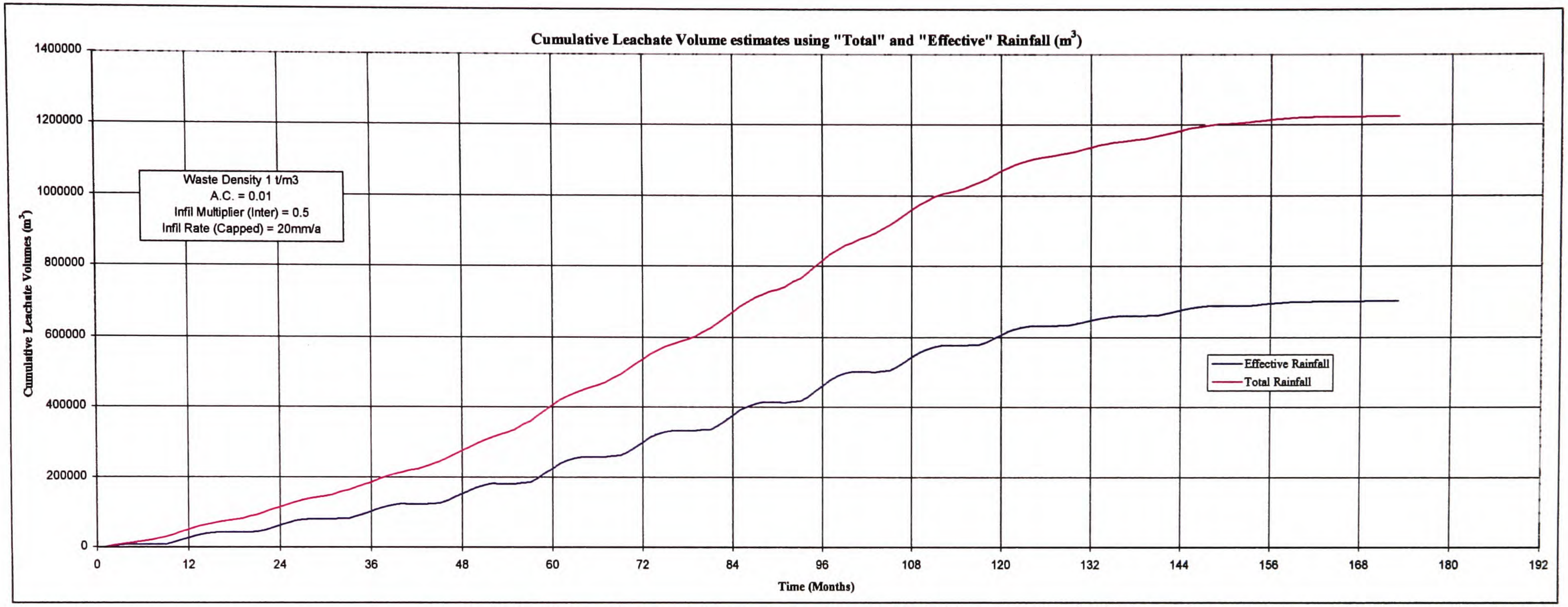
TITLE
MONTHLY LEACHATE VOLUME / FLOW RATE ENVELOPES

DATE	MAR '99	PRODUCED BY	GJ
SCALE	NTS	CHECKED	KD
REF		APPROVED	KD

DRAWING NUMBER
BECCF*** / FIGURE 4



REV	DATE	General revision description	BY	CHKD	NOTES General notes to go in this box

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****** ****** ******** EXTENSION

TITLE
PREDICTED CUMULATIVE LEACHATE VOLUMES FOR "TOTAL" AND "EFFECTIVE" RAINFALL CONDITIONS

DATE	MAR '99	PRODUCED BY	GJ
SCALE	NTS	CHECKED	KD
REF		APPROVED	KD

DRAWING NUMBER
BECCF026/ FIGURE 5

APPENDIX 3

Example of Geotechnical Review for a Major Landfill

AUTHORITY ********: ENVIRONMENTAL PROTECTION DEPARTMENT

******** ******* EXTENSION

GEOTECHNICAL REVIEW AND STABILITY ASSESSMENT

March 1999

Prepared by :
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Prepared for :
Authority *******

AUTHORITY ********

Report Title	:	******** ******* Extension Geotechnical Review and Stability Assessment
Report Status	:	Consultation Release : Version 1
Date of Issue	:	March 1999
Job No.	:	BECCF***.***
Prepared By	:	.... (A Dolecki / D Gill)
Checked by	:	.... (K Davies)
Check Cat.	:	B
Approved by	:	.... (A Dolecki)

CONTENTS

Figures

Appendices

1 INTRODUCTION

1.1 General

1.1.1 PB Kennedy & Donkin Limited (PBKD), was instructed by ****** Limited on behalf of Authority ******** to carry out a stability assessment of the proposed Eastern Extension to the ******** Landfill Site.

1.1.2 The Terms of reference for the work are presented in a Fax from **** Limited, dated December 1998 and in our full proposal letter dated January 1999, which was prepared in response to a scoping phase of PBKD's 'review appointment'.

1.1.3 This report presents a review of previous work carried out by others for the Separation Layer and the ***** Extension and presents further stability analyses to provide a single consolidated assesment. It is further intended to address the comments made in the Environment Agency (EA) letter to Authority ******** Ref **** dated October 1998.

1.2 Scope of Work

1.2.1 In order to provide a single consolidated stability assessment and address the comments of the Environment Agency the following scope of work has been established:

- Review parameters and values used in the various stability assessments previously undertaken
- Undertake contemporary literature search to comment on soil / waste properties and values previously selected
- Comment on appropriateness of soil property values previously used
- Review and make comment on software packages previously used
- Undertake check analysis of previous slope analyses
- Undertake sensitivity analysis using a range of soil strength parameters and piezometric surfaces.
- Provide recommendations for further complex soils analysis where considered necessary.
- If appropriate, develop mitigating operational / temporary support methodologies, ongoing stability monitoring and the need to update analyses as development proceeds.

1.3 Site Details

1.3.1 ******** Landfill Site is located approximately 3.5 km to the east of ????? City Centre, accessed via ********. The proposed 21 ha total extension to the site, envisaged to provide tipping space for the next 15 years is currently under construction. The National Grid reference for the centre of the ***** extension is *******. A 'Separation Layer' is required at the interface of the proposed Eastern Extension and the existing (old) 'western landfill' area.

1.3.2 At the time of writing, engineering works to prepare Cell 1 of the ***** Extension is nearing completion, with the separation layer effectively complete for all but a final layer of drainage geocomposite and drainage stone along its southern section, beyond Cell 1. The eastern bund and leachate collector drain and manholes are in place along the eastern side of Cell 1 and the cell base is at formation level and substantially covered with drainage geocomposite and drainage stone.

2 REVIEW OF AVAILABLE INFORMATION

2.1 Previous Stability Assessments

2.1.1 The following stability assessment reports relating to the eastern extension were made available by Authority ********.

- Preliminary Stability Assessment of Proposed Extension and Additional Tipping Areas - May 1995. Consultant A.
- Stability Assessment of Proposed Extension and Additional Tipping Areas - July 1995. Consultant A.
- Preliminary Deformation Study of Ground Beneath a Sewer - August 1995. SI Contractor A in association with Consultant B.
- Report on Hydrogeological and Geotechnical Investigation - October 1995. SI Contractor A in association with Consultant B.
- Stability and Deformation of Ground Along the Eastern Boundary - November 1995. SI Contractor A in association with Consultant B.
- ******** Landfill ***** Extension, Slope Stability Analysis at Toe Trench. March 1998. Consultant C.
- Stability of Excavations Adjacent to Separation Layer ******** Landfill, Cardiff. May 1998. Consultant C.

2.1.2 Both the Consultant A reports examined the stability of slopes formed by proposed eastern extension to the landfill site. The preliminary stability assessment used 'original geotechnical parameters' obtained during site investigation for the sea wall bund (reported in their 1986 Final Design Report) along with assumed parameters based on the effect of consolidation of the underlying alluvial clay due to the weight of overlying fill. These parameters are shown in Table A in Section 3. A further stability report was carried out with the benefit of additional geotechnical information gained from a site investigation by SI Contractor A conducted in June 1995.

2.1.3 The additional parameters obtained were found to be in 'close correlation' with the assumed parameters used in the preliminary assessment.

2.1.4 The Consultant A stability assessment carried out analyses on two sections considered to represent the 'worst case' final conditions, indicated in their report as 'Section 3' through the existing southern side slope of the existing western landfill and 'Section 13' through the proposed final profile of the eastern side slope of the eastern extension.

2.1.5 The following conclusion and recommendations were made in the Consultant A report:

a *Raising the level of the existing landfill, adjacent to the southern bund, from 16 m to 25m A.O.D will not lead to overall slope instability.*

b *Based on the information currently available, filling in the proposed eastern and north eastern extensions to the landfill should be planned to comply with the following:*

Filling Rate	Max Fill ht (m AOD)
0.5 m/yr	31 (max proposed)
1.0 m/yr	31 (max proposed)
1.5 m/yr	31 (max proposed)
2.0 m/yr	16*
>2.0 m/yr	11*

* *Having filled to the levels shown for rates exceeding 1.5 m/yr, an additional small site investigation should be carried out to confirm the calculated rates of strength gain in the clays. It may then be possible to continue filling albeit at a reduced rate.*

2.1.6 No analysis was carried out on the stability of the intended interface of proposed and old landfills at that time.

2.1.7 No information is provided on the name of the software package used for the stability analyses, or the method of analysis that has been employed by Consultant A ie. Bishop or Janbu etc.

2.1.8 The October 1995 report by SI Contractor A and Consultant B presented the results of a site investigation for the eastern extension and addressed design issues relating to containment of leachate, containment of hazardous gases, and earthworks design and stability (settlement in this case).

2.1.9 The November 1995 report by SI Contractor A and Consultant B carried out analysis for both slope stability and deformation (using geotechnical parameters from the earlier report) on a section through the proposed eastern boundary considered to represent the worst case geometry (from proposed restored contours).

2.1.10 Analysis of consolidation and ground deformation was carried out using 'PLAXIS' (Version 5.1), a general purpose finite element computer program. The stability of slopes to the landfill and the proposed reen was analysed with 'SLIP5' a slope stability computer program, which performed effective stress analysis based on Bishop's routine method for circular slip surfaces. Both programs are proved and tested industry standards.

2.1.11 The report concluded the following:

- *Reen slopes excavated to 1 in 1.5 are stable in the general condition. Localised slope failures however may occur owing to variations in the ground conditions and some repair and general maintenance of slopes should be anticipated. More stable slope configurations are outlined.*

- *Deformation analyses indicate that where the reen is excavated to within 13 m of the sewer, the ground movements beneath the sewer are likely to be of the order of 5 mm. Where the landfill embankment is placed to within 28 m of the sewer, the lateral displacement of ground beneath the sewer may be a further 2 mm.*

- *It is possible to construct the landfill embankments to its full height within the time frame indicated by the Authority **** in their working plan, for the conditions assumed in the analysis. There may however be a significant risk of slope failures where the methods of working are different to that being assumed or where the assumed ground conditions do not prevail. To manage this risk in a safe and efficient manner, it is recommended that further detailed analyses are carried out to optimise the sequence of construction activities and to allow the establishment of a monitoring strategy for the site.*

2.1.12 The report did not consider the stability of the interface between the proposed and old landfills (ie. the separation layer).

2.1.13 The Consultantr C report considers the stability of the separation layer with respect to excavations at the toe of the interface slope. This is required to increase the available void space within the new Eastern Extension Cell. This report does not comment on the post restoration stability of the eastern slope to the landfill extension. The analyses have been undertaken using the GPSSP (General Purpose Slope Stability) program from the Department of Environment Handbook on the Design of Tips and Related Structures (HMSO, 1991) and is based on a 'typical section' through the separation layer and not on actual survey data. The individual components used in the construction of the separation layer have been not considered in the 'typical section' for analysis.

2.1.14 Geotechnical parameters of the underlying clays have been extracted from site investigations undertaken by SI Contractor A in 1995 and 1997/1998. Waste unit weight and strength parameters are reported as being 'figures used in the Practice previously'. There is no clear tabulation of soil parameters used in the analysis; no leachate levels taken into account; confusing references to biplanar and spiral failures for no apparent reason.

2.1.15 The Consultant C report concludes the following:

- *The stability of the batter to the eastern landfill is marginal with open excavations as close as 10 m to the toe of the slope.*

- *No extensive excavation of 2 m depth (or greater) should be considered within 15 m of the toe of the landfill.*

- *Short (less than 10 m) lengths of excavation, open for limited periods (and no more than 2 days) are feasible at closer distances provided they are no deeper than 2 m.*

2.1.16 The validity of these statements are discussed in later sections of this report in relation to both current construction practice and observational effects.

2.2 Published Research

2.2.1 The following publications which represent some of the most recent research in the stability of waste, have been reviewed to compare and where necessary refine parameters used in the following stability analyses:

- Landva A.O and Clark J.I. 1990. Geotechnics of Waste Fill, in Geotechnics of Waste Fills, Theory and Practice, (eds. Landva and Knowles). ASTM STP 1070

- Oweis I.S. 1993. Geotechnical Practice for Waste Disposal, (ed David E. Daniel). Published by Chapman & Hall

- Koda E. 1998. In-situ tests of MSW geotechnical properties, Green 2, Published by Thomas Telford London

3 REVIEW OF GEOTECHNICAL PROPERTIES

3.1 Alluvial Clay

3.1.1 The in situ clay underlying ******** Landfill Site which forms the base to the existing landfill to the west, will form the low permeability 'basal liner' to the Eastern Extension. In order to maximise void space, the base of the Eastern Extension has been formed by excavating into the alluvial clay crust to a depth of 2m (4m AOD) below existing ground level. This clay was used as a component in construction of the recent Separation Layer. Alluvial clay won from the excavation of the mitigation reen was used in construction of the eastern landfill bund.

3.1.2 Table A below lists the unit weight and strength parameters asigned to the alluvial clay which have been used in the various stability analyses to date:

Report Author	Material Properties					
	Unit Weight kN/m^3	Undrained Cohesion cu (kN/m^2)	Angle of Shearing Resistance (Degrees)	Effective Cohesion c' (kN/m^2)	Effective Angle of Shearing Resistance Ø'	Notes
Consultant A						
Clay Bund	16	25	0	-	-	
Alluvial Crust	17	15	0	-	-	(z=depth)
Virgin Alluvial Clay	16	6 + 2 z	0	-	-	assumed
Consolidated Alluvial Clay	16	16 + 2 z	0	-	-	assumed
Consultant B						
Alluvial Clay	17	37	-	0	22	
Consultantr C			-	-	-	
Very Strong Clay Crust	18	15	-	-	-	
Weak Clay Crust	18	8	-	-	-	
Very Weak Clay	18	6	-	-	-	
Gradually Strengthening Clay	18	15	-	-	-	
Gradually Strengthening Clay	18	45	-	-	-	

Table A Summary of Clay Parameters for Stability Analysis

3.1.3 As part of the stability assessment review, PBKD carried out in-situ hand vane tests at the site in January 1999, in order to gain additional information on the undrained shear strength (cohesion) values for the alluvial clay. A total of 40 No. hand vane tests were taken at regular spacings across the base of Cell 1 at a depth of 0.2m below the 4.0m AOD formation level.

3.1.4 The undrained cohesion of the clay was measured ranging from a lower end value of 26kN/m^2 to an upper end value of 102kN/m^2 with a mean value of 59kN/m^2. At the time the hand vanes tests were undertaken, the cell floor had been exposed to prolongued rainfall since excavation to the final 4m AOD level and had been submerged below ponded rain water for a number of weeks. Softening of the upper surface of the clay was apparent.

3.2 Waste

3.2.1 It is understood that ******** currently receives a total of 300,000 tonnes of waste per annum, of which 130,000 tonnes is domestic waste, 130,000 tonnes is classified as soil and slag and 40,000 tonnes is classified as undifferentiated commercial / domestic waste.

3.2.2 Table B below summarises the unit weight and strength parameters used in the various stability analysis to date.

Report Author	Material Properties				
	Unit Weight (kN/m^3)	Undrained Cohesion Cu(kN/m^2)	Angle of Shearing Resistance (Degrees)	Effective Cohesion c' (kN/m^2)	Ø'Effective Angle of Shearing Resistance (Degrees)
Consultant A					
Recent Fill	12	0	20	-	-
Older Fill	15	0	20	-	-
Consultant B					
Waste	10	-	-	0	25
Consultant C					
Waste	10	0	45	-	-

Table B Summary of Waste Parameters for Stability Analysis

3.2.3 The geotechnical properties of waste can be difficult to determine due to its inherrent heterogeneity. However, recent work by Landva and Clarke 1990, is considered to provide some of the most reliable parameters for waste fill, being based on both laboratory and full scale in situ tests. Large direct shear tests indicate that for various waste types from Canadian landfills, values for the angle of shearing resistance range from 27° to 41°. It is considered that the value of 45° used by Consultant C is however an over estimate for the typical waste fill characteristics present at the ******** Site.

3.3 Geomaterials

3.3.1 Previous analyses carried out have not allowed for the presence of the geomaterials within the separation layer and eastern bund. Reference to the published literature (Section 2) suggests that the Ø value for geotextiles on fine grained soils are the same as the angle of shearing resistance of the soil as the soil particles tend to get lodged in the fabric. Therefore, the lowest shear strength values along an interface are likely to occur between the HDPE and protection geofabric and values ranging from 6° - 24° have been reported.

3.4 Sensitivity of Parameters

3.4.1 A range of parameters has been selected for the PBKD stability analysis to include values used in previous analyses by others and values obtained from the published research (Section 2) considered appropriate for the ******** Site. Subsequent analysis has tested the sensitivity of these ranges of values which are presented in Table C in Section 6.

3.4.2 The properties of the 'competent and dense' underlying gravels are not deemed to be sufficiently sensitive as to influence the overall stability of the landfill development and are not therefore discussed further.

4 METHOD OF ANALYSIS

4.1 Method of Analysis

4.1.1 The methods used for the analysis of slope stability by PB Kennedy & Donkin Limited are those published by Bishop and by Janbu et al 1956. The Bishop method of analysis is based on circular slip surfaces and can be used for either total stress or effective stress conditions. With this method and the use of a computer program many hundreds of different slip planes can be analysed in one run. The Bishop method is recommended for all routine problems. Janbu's method is applicable to circular and non-circular slip surfaces and can determine the factor of safety against instability of a slip surface of any shape. It is considered that these methods of analysis are appropriate for the stability assessment of the Separation Layer and the Eastern Extension.

4.1.2 The slope stability assessment carried out by PBKD uses the Bishop and Janbu methods of analysis from the SLOPE suite of computer programs written by D L Borin and distributed by Geosolve Software.

4.1.3 This suite of programs is routinely used by PBKD in the analysis of slope stability problems in waste fills and has been found to be completely satisfactory.

4.1.4 Both short term (undrained) and long term (drained) parameters were considered in the analysis, but it is the undrained situation that is considered to represent the 'worst case scenario' where the lowest factors of safety could be expected.

5 GEOMETRY OF CROSS-SECTIONS

5.1 General

5.1.1 The stability analyses have been carried out on a selection of sections through the Eastern Extension cell in order to model the various current site conditions and proposed geometry. The models reflect the detailed construction of the separation system and eastern bund along with proposed final restoration contours for the Eastern Extension.

5.1.2 A total of 5 No. Sections have been prepared using recent survey data and proposed final profiles (Drawing No. SEW 239.LWEE.11) provided by Authority ********. A plan indicating the lines of section is presented as Figure No. 3.

5.1.3 Construction details from the design drawing and 'as built' drawings has enabled several sections to be prepared which accurately reflect the geometry of the separation layer, eastern extension and the spatial distribution of the various construction material and underlying ground conditions at each location.

5.1.4 Given the proposed final restoration contours for the site, it is considered that circular slip planes are more likely to have lower factors of safety than non-circular failure planes in the high waste slope. However, specified non-circular failure surfaces have also been analysed including a potential slip surface at the low friction interface between geomaterials in the separation layer.

5.2 Separation Layer

5.2.1 The separation layer has been modelled along three sections (Sections A-A, E-E; and H-H). Section A-A is taken through the northernmost extent of the separation layer, where fill to the north of the layer is not proposed to exceed the maximum height of the bund and where restored profiles indicate waste fill in the Eastern Extension at a gentle gradient of approximately 7°.

5.2.2 Sections E-E and H-H are representative sections taken through the separation layer considered to represent the current site conditions. Once waste is placed against the separation layer the likelihood of instability will have been greatly reduced.

5.3 Eastern Bund

5.3.1 The eastern bund to the extension has been modelled along Sections B-B and F - F. These sections are considered to represent the most critical situation where restoration contours indicate waste fill up to a proposed maximum height of 31 mAOD forming an approximate 15° waste slope.

5.4 Geology

5.4.1 For the purpose of the PBKD analyses, the depths to the various strata below the eastern extension has been based in general accordance with the findings of cable percussion borehole No.42, from the 1995, SI Contractor A/ Consultant B work. The borehole record indicates that the alluvial clay was encountered to a depth of -2.46m O.D overlying a thin (0.2m) layer of peat in turn overlying sand and gravel.

5.4.2 The Consultant B ground model for stability analysis was also based on the findings of borehole No. 42 of the 1995, EAH work

5.5 Groundwater and Piezometric Surfaces

5.4.1 Groundwater levels within the clays and gravels have been based on the site investigation data presented in the 1995 Contractor A/Consultant B report. In addition to a groundwater level, the SLOPE software package allows up to 4 different piezometric surfaces to be modelled at once. Various piezometric surfaces representing leachate build up within the waste have been considered during the analysis of the separation layer and the post restoration eastern bund.

5.4.2 Piezometric surfaces representing leachate within the existing western landfill waste mass have been modelled to simulate its effective drainage via the lower drainage geocomposite to the toe drain. Further analyses have considered the effect on stability of blocked or defective underdrainge to the separation layer, with a piezometric surface representing leachate levels at 10m AOD.

5.4.3 Piezometric surfaces representing leachate in the waste mass, within the Eastern Extension have been modelled at 7m AOD (3m above the cell base), and 10m AOD (greater than the height of the eastern bund).

6 STABILITY ANALYSIS AND FACTORS OF SAFETY

6.1 Separation Layer - Circular Failures

6.1.1 Circular failures through the waste mass and underlying alluvial clays have been analysed for two different geometries based on section E-E (Figure 6) and section H-H (Figure 8). Section E-E represents the completed separation layer where the final layer of drainage geocomposite and drainage stone have been placed and the cell floor excavated to the 4.0m AOD level with the 2m high, 10m wide stand off. Section H-H is through the southern end of the separation layer where at the time of survey and analysis, the final layer of drainage geocomposite and drainage stone had not yet been applied and the 2m excavation had not yet been made.

6.1.2 Factors of safety were calculated for the lower and upper range of strength parameters and unit weights presented in Table C, for the model are presented by section E-E, considered to be the most critical situation, ie. before waste has been placed into the new eastern cell. It is considered that the upper range of values are more realistic. For the lower range, a minimum factor of safety of 1.6 was calculated, which allowed for a piezometric leachate surface of 4m AOD within the waste mass. Failure of the drainage geocomposite and toe drain at the underside of the separation layer would be required to enable the piezometric head as used in the analysis to develop. This is considered unlikely in the short term.

6.1.3 Additional analysis assigning the strength parameters chosen by Consultant C has been carried out. For the purpose of their analysis Consultant C did not differentiate between the different materials in the separation layer. Therefore to emulate this the same Consultant C strength parameter has been assigned to each component, ie. C = 0 , Ø = 16, whether soil or geomaterial. The Consultant C strength parameter of 45° has been assigned to the waste mass.

6.1.4 For a circular failure through the toe of the separation layer a minimum factor of safety of 1.6 was calculated using Consultant C strength parameters and the as built geometry of section E-E. This is significantly greater than the 1.07 factor of safety indicated in the Consultant C report for 2m excavations with a 10m bench width.

6.1.5 Only the lower range strength parameters were used for the analysis of circular failures for section H-H as factors of safety calculated were found to be more than satisfactory. For a circular failure through the waste mass, into the underlying alluvial clays, exiting at the toe of the separation layer with a piezometric leachate surface specified at 7.0m AOD, a minimum factor of safety of 2.2 was calculated. Additional analysis varying the piezometric leachate surface to an elevated level of 10.0m AOD (an unlikely scenario, particularly in the short term), resulted in a minimum factor of safety calculated at 1.8 .

6.1.6 The full results of the analysis are presented in Appendix 1.

	Short Term (Undrained)		Long Term (Drained)		Bulk Density
Material	Cu (kN/m^2)	ϕ	c'	ϕ	γ kN/m^3
Waste	0	20-27	0	25	10 - 15
Drainage stone	0	16-33	0	16-33	16-20
Clay Cover	8-25	0	0	22	18-21
Geomembranes	0	6-8	0	6-8	10*
Compacted Clay	15-25	0	0	22	16-20
Clay Bund	15-25	0	0	22	16-20
Alluvium	6-26 #	0	0	22	16-20
Gravel	0	30-45	0	30-45	18-20

	Min F for Strength Values		Min F for Strength Values	
Condition	Lower Bound	Upper Bound	Lower Bound	Upper Bound
Separation Layer Circular	1.6	3	+	
Separation Layer Non-Circular Interfacial	1.2 1.56	1.75	+	
Eastern Bund Circular	1.28	2.10	+	
Eastern Bund Restored Profile Circular	1.28	2.10	+	
Eastern Bund Restored Profile Non-Circular	1.39	2.2	+	

	For F<1.0 = For Bund Failure		
Circular failure Eastern Bund	Cu	ϕ	F
Waste	0	27	
Clay Bund	3	0	0.87
Alluvium	6	0	

Table C Summary of Analysis and Factors of Safety (F)
* assumed value > unit weight of water, required by program
# lowest hand vane recorded on cell floor of eastern extension.
+ Factor of safety considered too great to be of concern

6.2 Separation Layer - Non Circular Failures

6.2.1 As shown on Figures 4,6 and 8, in addition to reworked alluvial clays and drainage stone, the separation layer is made up of drainage geocomposites , geomembranes and geogrid reinforcement. The factor of safety against sliding along the soil/geomaterial and geomaterial / geomaterial interface has been considered. The interface friction angle depends on the type of materials on both sides of the interface, however in the case of the separation layer it is considered that the most critical interface exists between the HPDE and Abtex protection geofabric.

6.2.2 Previous reports have not considered failures of this type. However, inspections of the separation layer in Cell 1 during a site visit by PBKD revealed what appeared to be small slumps in the surface of the clay cover to the separation layer at the southern end where the final layer of pozidrain and drainage stone had not yet been placed. The reworked alluvial clay cover had been subject to heavy rainfall and showed evidence of erosion and it was considered that the "slumps" may have been due to movement along the underlying HDPE / Abtex interface.

6.2.3 A minimum factor of safety of 1.56 was calculated for (non circular) failure along the HDPE/Abtex interface using the lowest potential parameters for the angle of shearing resistance presented in Table C. Further analysis considering an elevated piezometric leachate surface within the waste below the separation layer was not necessary due to the presence of an underlying pozidrain layer connected to a toe drain effectively preventing a build up of leachate of this kind.

6.2.4 The analysis is likely to be an underestimate of the factor of safety as the program used could not adequately model the effect of the anchor trench. For interfacial failures to occur it would require a continuous tear to be made through the HDPE or protection geofabric beyond the crest.

6.2.5 In view of the factor of safety of 1.56, it is considered that the small "slumps" noted on the exposed cover layer are due to softening of the clay and erosion by rain water.

6.2.6 General non circular slip surfaces have been specified by PBKD for the separation layer. The geometry of the section modelled accounts for the geomaterials within the separation layer, the gain in strength of the underlying alluvial clays with depth and allows for a leachate piezometric surface within the waste mass draining to the toe drain. The non circular slip surface was specified by three points, starting at the crest of the separation layer passing through the waste mass into the weakest alluvial clay horizon and exiting at the toe of the separation layer.

6.2.7 From the analysis, using strength parameters considered to reflect the lower bound values for the waste mass and geomaterials, a factor of safety of 1.2 was calculated. Using more realistic strength parameters from the upper bound range of values listed in Table C, a factor of safety of 1.7 was calculated against non circular failure.

6.2.8 The full results are presented in Appendices 2 and 3.

6.3 Eastern Bund - Circular Failures

6.3.1 The stability of the landfill along the eastern bund once the final proposed restoration levels have been achieved is of prime concern and PBKD have carried out various analyses for circular failures for geometries based on sections B-B and F-F for both pre and post restoration contours. The analyses have shown that stability of the bund prior to waste filling is not in question. For circular failures to occur through the bund unrealistically low strength parameters would be required for the clay core.

6.3.2 The restored profile superimposed onto Section F-F represents, the maximum height of proposed waste filling to the 31m AOD contour. The minimum factor of safety against circular failure through the waste mass for the lower range of strength parameters, with a piezometric surface for the leachate within the waste at 7.0m AOD (i.e. 3m above the base of the eastern extension cell) was calculated at 1.28. By raising the piezometric surface for the leachate to 10m AOD, (an unlikely scenario considering that at such levels, leachate would be above the bund) and using lower range strength parameters a minimum factor of safety of 1.19 was calculated.

6.3.3 Analyses for circular failure adopting the upper range strength parameters resulted in a calculated minimum factor of safety of 1.9 for a failure through the edge of the waste mass and factors of safety in excess of 2 for failures passing through the waste mass into the underlying alluvial clay.

6.3.4 The full results are presented in Appendices 4 and 5.

6.4 Eastern Bund - Non Circular Failures

6.4.1 Non Circular failures were specified by PBKD extending through the waste mass into the weakest layer of the underlying alluvial clay, exiting at the toe of the eastern bund. The analysis for the upper and lower range of parameters considered a piezometric level of 7.0m AOD for leachate within the waste. The minimum factor of safety calculated for a specified non circular failure using lower range strength parameters was 1.39 and for upper range strength parameter was 2.2.

6.4.2 The full results are presented in Appendix 6.

7. SETTLEMENT AND DEFORMATION

7.1 Settlement Model

7.1.1 As deposition of waste in ******** cell extension proceeds, in addition to the settlement in the waste which will be of the order of 10-25% of the full height, the alluvial clay underlying the site will also be subject to an increase in total stress and consequently consolidation settlement will occur. To give an indication of the likely order and pattern of settlement, a spread sheet model has been created representing a phased programme of waste placement. The model is only intended as a general indication to enable the establishment of appropriate monitoring at the site. Computer analysis using the method of finite differences would enable a more accurate calculation of settlement due to stage loading. However, to validate accurate analysis of this nature further in situ and laboratory tests on consolidation properties at the site would be required to provide reliable input data.

7.1.2 The ***** Extension is now underlain by approximately 8.0m of normally consolidated alluvial clay since removal of the upper 2.0m (of 'stiff' crust) was carried out to increase available void space.

7.1.3 A 2m thick gravel stratum is present beneath the clay considered to represent a permeable drainage layer. The leachate drainage system for the eastern extension comprises a number of gravel filled drainage channels spaced at regular interval, along with a drainage geocomposite and 300mm drainage stone cover across the whole of the cell base, which flow to a HDPE leachate drain aligned along the toe of the eastern bund. Therefore dissipation of porewater from the clay due to increasing applied load is considered to be under conditions of double drainage.

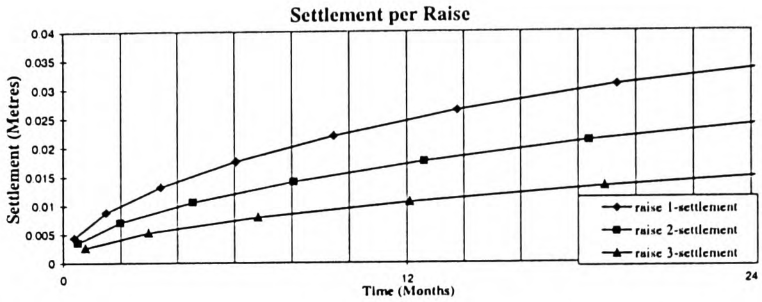
7.1.4 The rate and extent of settlement arising from a volume change in soil involve the three dimensional flow of porewater and three dimensional strain of the soil mass. However, it is generally sufficient to base the prediction of settlement using the one dimensional case from the results of soil tests in a laboratory oedometer. Oedometer tests carried out on soils recovered from a site adjacent to ******** have provided the typical consolidation parameters c_v, the coefficient of vertical consolidation and m_v, the coefficient of volume compressibility.

7.1.5 These parameters have been used with standard equations which have been incorporated into spreadsheet calculations to provide a preliminary projected consolidation model for the staged placement of waste to the Eastern Extension. The preliminary model considers a filling plan in which convenient 75m wide panels of 2.0m waste raises are constructed across the cell base from the haul road in the south west corner of Cell 1.

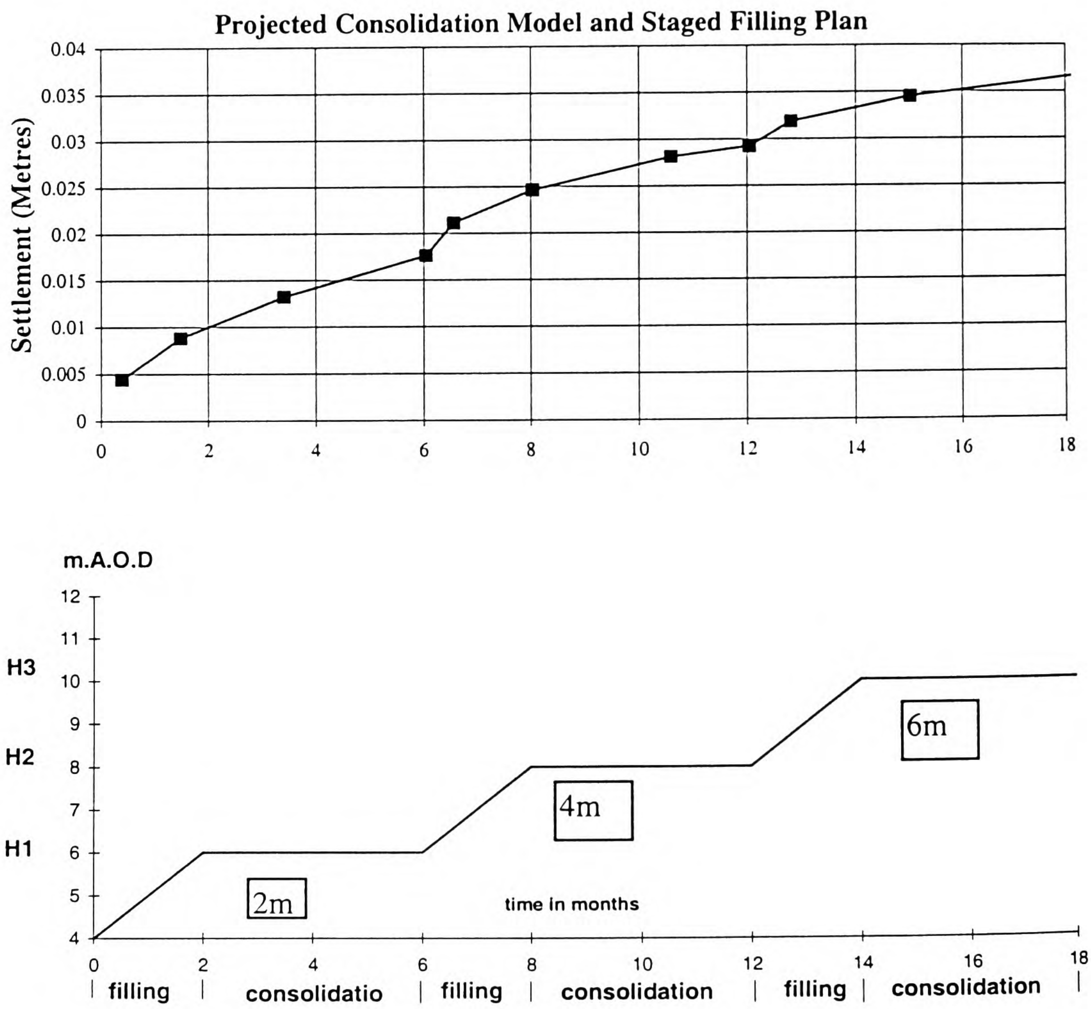
7.1.6 Given that the site is likely receive a total of up to 300,000 tonnes of waste per annum and that the total tipping area of Cell 1 is initially 19,000m2 increasing with height to 52,552m2 and an average tipping surface area for any one raise of 35,500m2, for a compacted unit weight of waste of $10kN/m^3$, a full 2.0m lift of waste should be complete in approximately 2 to 3 months. Therefore, a second raise of waste could be placed starting at the first panel on completion of each full raise in Cell 1 say some 4 to 6 months after placement of the first lift /raise. The model considers the pattern of settlement consolidation for the first three raises only.

7.1.7 Graph 1 indicates the degree of settlement likely to occur for each raise of waste against time (in months) for up to 90% consolidation complete within approximately 24 months. Graph 2 however indicates the likely combined degree and pattern of consolidation for three consecutive raises every six months but without allowing 90% consolidation to have taken place at each stage. Hence total settlement increases with time, but incremental settlement will generally decrease as the clays become stronger, less permeable and less compressible with time and increased staged loading. This is an ideal model for a uniform and homogeneous soil but however, in practice this process is far more complicated; consolidation times can decrease or increase depending on actual material characteristics which may vary across the site.

7.1.8 In order to gain a full appreciation of the magnitude and pattern of consolidation settlement and the subsequent effect on the geotechnical characteristics of the underlying alluvium, a long term monitoring program should be put in place with the establishment of permanent settlement monitoring stations.



Graph 1



Graph 2

8 CONSTRUCTION AND OPERATIONAL ASPECTS

8.1 Tipping and Phasing

8.1.1 Based on the information currently available from Authority ********, the stability and deformation assessment and recent work by PBKD at Pengam Green for a new housing development, it is envisaged that tipping will be phased along the pragmatic guidelines shown in Figure 10. Each panel (up to 75m in width) should be filled (raise 1) over a period of say 2 (to 3) months with lifts / raises of up to 2m in height. A consolidation period of at least 4 months (possibly 6 months) should be made available prior to filling to greater heights (raise 2). This should allow sufficient time for porewater pressures to reduce, enabling consolidation to take place, thus allowing a gain in clay shear strength with time and increasing waste height/loading.

8.2 Monitoring and Instrumentation

8.2.1 In order to verify that the above is satisfactory, a programme of monitoring using appropriate instrumentation should be established at the site and regular and detailed data should be collected over the early phases of tipping. This will allow changes to be made to filling rates and policies which can be adjusted on observational factors and not purely on the model.

8.3 Verification of Shear Strength Gain

8.3.1 Baseline shear strength data on the alluvial clays currently exists. For the first two years after initial filling, an annual shear strength profiling in a number of boreholes could be performed to determine and confirm the degree of strength gain in the clays due to imposed loading from the waste mass.

8.4 Alternatives For Faster Rates of Filling

8.4.1 If the guidelines presented in this report on the anticipated rates of filling are currently or are likely to become unachievable, for faster rates of filling then consideration may need to be given to improving the performance of the alluvial clays by reducing or accelerating the consolidation and increasing the shear strength of these materials by use of ground treatment processes such as vertical band drains or the introduction of lime columns. Careful environmental considerations would however be required prior to their use.

8.5 Observed Stability and Excavation Performance

8.5.1 The Consultant C report makes several recommendations with regard to the stability of excavations (Section 2.1.15). These have not been borne out on site. Excavation lengths up to 150m long, up to 2m deep have been open and stable for some 6 months, the majority of this time in wet weather conditions. Whilst stability appears to be improved, the materials performance on working has been difficult, neccessitating the use of lime additives to the clay in "poor" areas of the cell base, which has greatly enhanced workability, strength and performance during winter months. The use of observational methods in geotechnical engineering can therefore provide meaningful results for construction and operational considerations.

9. CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

9.1.1 PBKD have peer reviewed the available reports and carried out stability analyses for a range of geometries for the Eastern Extension in order to provide a uniform and consistent approach to the determination of factors of safety for slope stability at the site. The review has confirmed that it is possible to construct the landfill to its full height.

9.1.2 Circular slip surfaces as analysed by both Consultant A and Consultant B are standard approaches to the specific ground conditions at the site. Consultant C's reference to 'spiral' (circular) and 'bi-planar' (non circular) terminology is confusing and an unnecessary complication of terms, more generally applied to rock slopes (not soil slopes), rock 'dumps' or spoil heaps.

9.1.3 PBKD have assessed by analyses, literature search, engineering judgement and back analysis of similar project criteria, the merits and sensitivity of the parameters (material properties), methods of analysis, landfill geometry, and resulting factors of safety for all three Consultants reports. With regard to Fill (Waste) Shear Strength (expressed as Ø), a Ø value of 45° (Consultant C) is considered to be an over-estimate. An upper bound value of 27° and a lower bound value of 20° is in this case considered to be appropriate. The sensitivity of this range has resultant factors of safety in the waste mass of 1.36 for lower bound values.

9.1.4 Both long term (effective stress - drained) and short term (total stress - undrained) stability has been analysed using both circular slip surfaces (Bishop), referred to as spiral by Consultant C and non circular (Janbu) referred to as bi-planar by Consultant C for a number of site conditions reflecting current Separation Layer geometry, Eastern Mitigation Bund geometry and final restoration geometry. The rigorous analysis undertaken in this current assessment provides a definitive review which has yielded the following results:

a The separation layer is inherently stable with factors of safety of 1.2 (1.2 - 1.6) at lower bound values.

b The eastern mitigation bund is stable with factors of safety of 1.3 at lower bound values.

c The final restoration profile has overall long term factors of safety in excess of 1.3 (1.3 to 2.3) at lower bound values.

9.1.5 With regard to overall stability and an underdrained waste mass, the underdrainage has been designed as a totally flexible system and, as such, should accommodate the degree of consolidation settlement that is envisaged. The preliminary settlement model indicates that for a phased cell construction with say 2 m high lifts, placed in workable panels over a period of 2 to 3 months, with an appropriate consolidation period (guided by monitoring data) between each lift, then ground deformation should not be excessive as to cause either instability in the foundation and internal earthworks or produce ground strains that could otherwise be detrimental to overall liner integrity. Internal cell haul roads should be carefully constructed taking into account the basic principles of staged filling. With regard to a rise in leachate level should the underdrainage become compromised, then it is unlikely that the waste mass would become unstable. Stability analyses have demonstrated that the sensitivity of leachate rise is not critical given the site conditions and design of the leachate drainage system. Leachate levels do however require effective control to ensure long term performance.

9.1.6 An analysis of the effect of the landfill on the existing sea wall at the southern boundary of the Eastern Extension has not been specifically undertaken as part of this report. It would appear that Consultant A's report considered two 'worst case' sections which did not include the sea wall. It is assumed therefore that this is not a critical section given the current site proposals.

9.1.7 In terms of short-term stability, particularly of say the eastern mitigation bund (and any internal bunds/earthworks), analyses has shown that worst case parameters where failure will occur (ie F<1.0) are extremely unlikely given the geometry, foundation and internal properties measured both in the laboratory and on site. The material forming the bund would need to be very soft and of such low shear strength and high moisture content such that it would 'exude between the fingers when squeezed'. Based on current knowledge and understanding only firm re-moulded clays were used for bund construction. The use of these firmer materials on site would render failure implausible. Factors of Safety in the short term are likely to be in excess of 1.3. Drained (long term) conditions are shown to provide more than adequate factors of safety.

9.1.8 Once staged filling and restoration is complete, long term stability should be further enhanced on the basis of excess porewater pressure dissapation, 90% consolidation settlement and sufficient strength gain in the alluvial clays with increased loading.

9.2 RECOMMENDATIONS

9.2.1 A programme of detailed monitoring should be defined and run alongside the phased filling operation in order to acquire relevant data which can be used to verify basic settlement predictions and where necessary adjust filling rates in future years. The programme should be sufficiently flexible to accommodate filling and operational requirements, but should be subject to on-going review and adjustment as necessary.

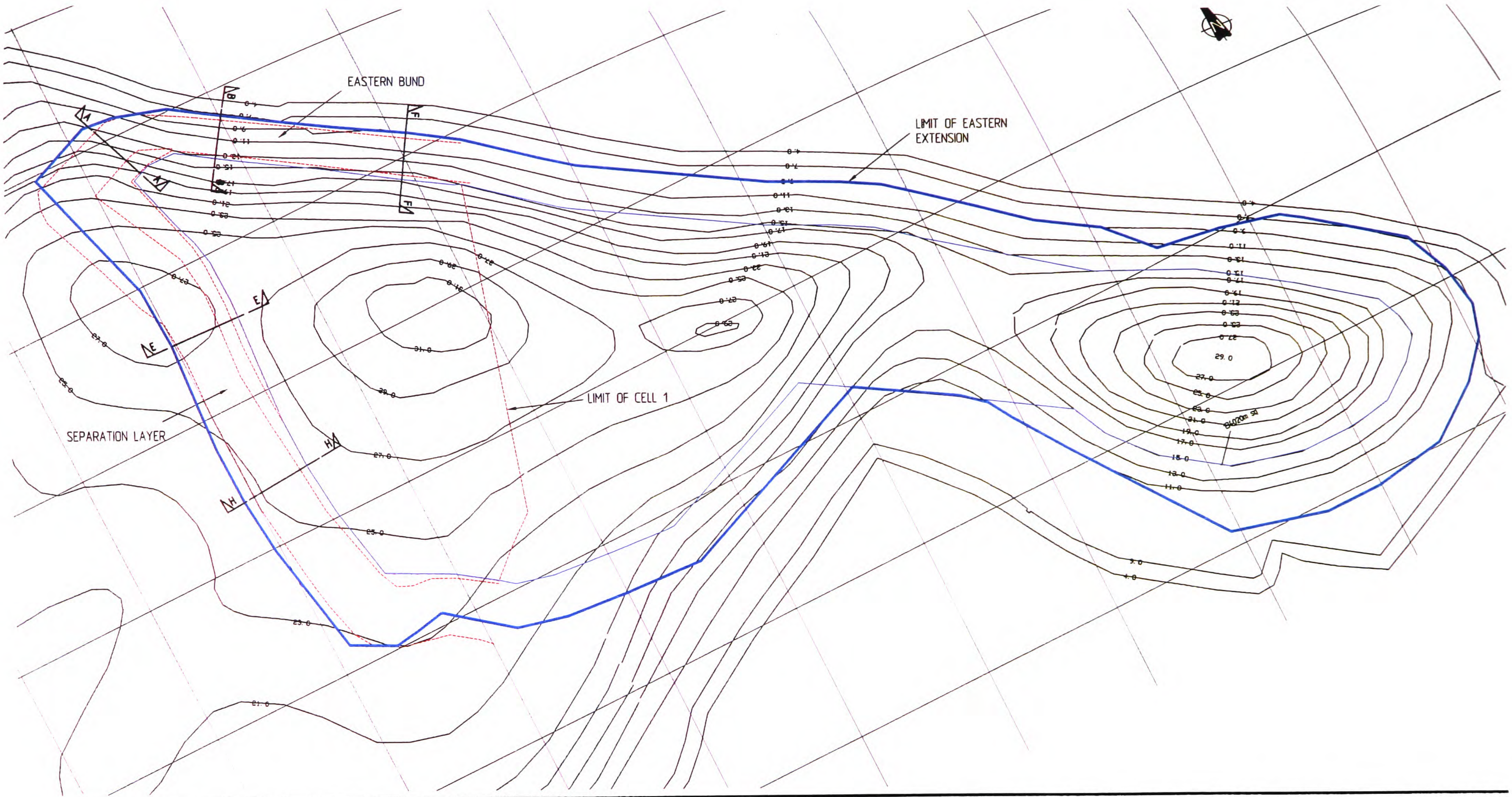
9.2.2 Additionally the theoretical settlement model could be greater refined by finite element analysis which should be subsequently verified by the monitoring of instrumentation to fully determine the magnitude of movement predicted by the computer analysis.

9.2.3 If the recommended settlement monitoring indicates any marked deviation from the predicted model then in order to verify or otherwise the gain in shear strength of the alluvial clays, shear strength profiling in a number of boreholes should be undertaken.

FIGURES

DETAILS LEFT BLANK

APPENDIX 3 - FIGURE 1: SITE LOCATION
(BLANK FOR CONFIDENTIALITY)



REV	DATE		BY	CHKD	• NOTES

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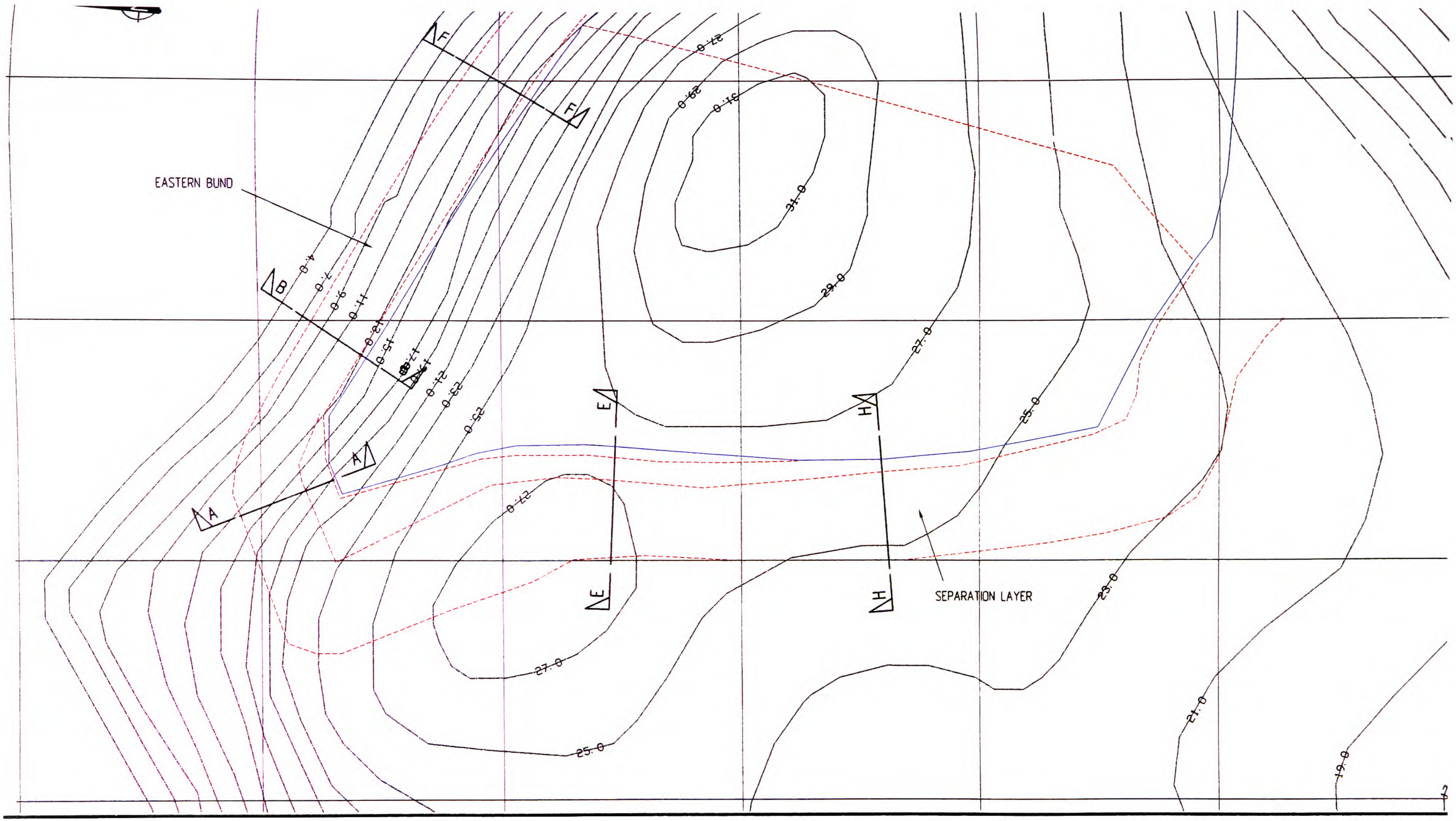
• CLIENT/PROJECT
ENVIRONMENTAL PROTECTION DEPT.

• TITLE
SITE PLAN SHOWING
RESTORATION CONTOURS
AND LINES OF SECTION

• DATE MAR '99
• SCALE 1:2500
• CAD REF. FIG2
PRODUCED BY AG
CHECKED
APPROVED

• DRAWING NUMBER
FIGURE 2



REV	DATE	BY	CHKD	• NOTES

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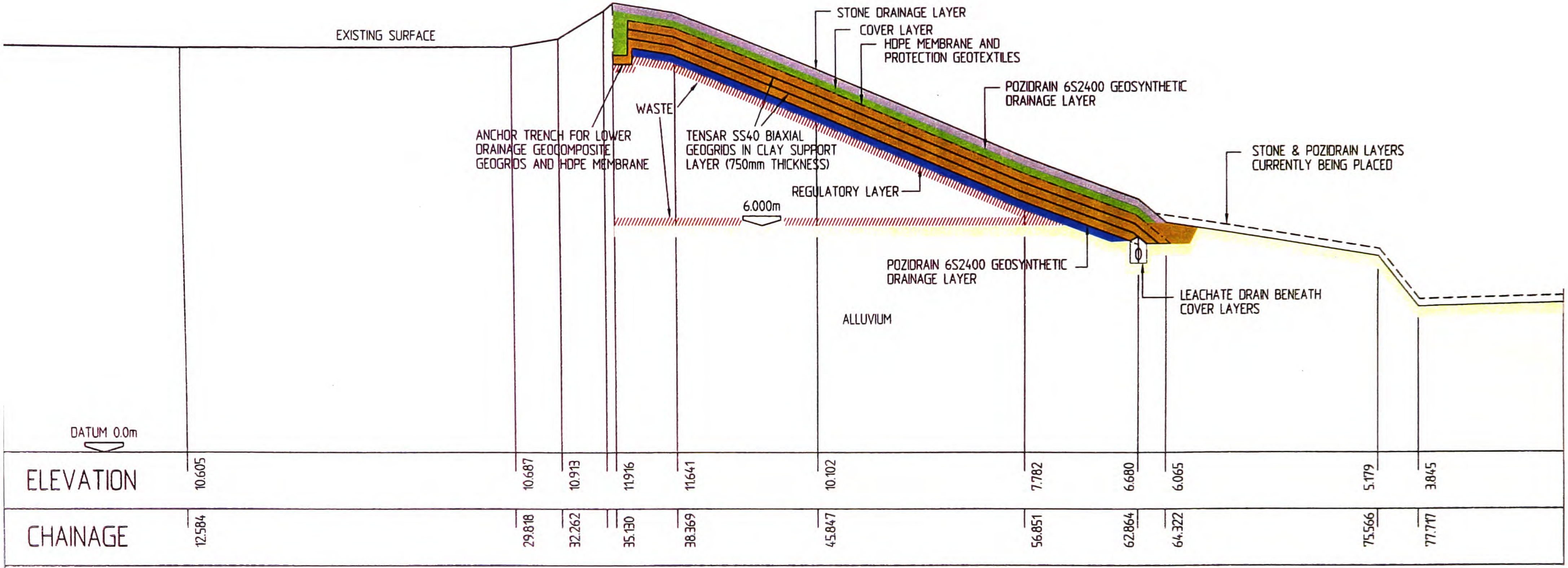
• TITLE
CELL 1
LINES OF SECTION

• DATE	MAR '99	PRODUCED BY	AG
• SCALE	1:1500	CHECKED	
• CAD REF.	FIG3	APPROVED	

• DRAWING NUMBER
FIGURE 3



SECTION A

SCALE 1:200 HORZ
1:400 VERT

REV	DATE	BY	CHKD	• NOTES

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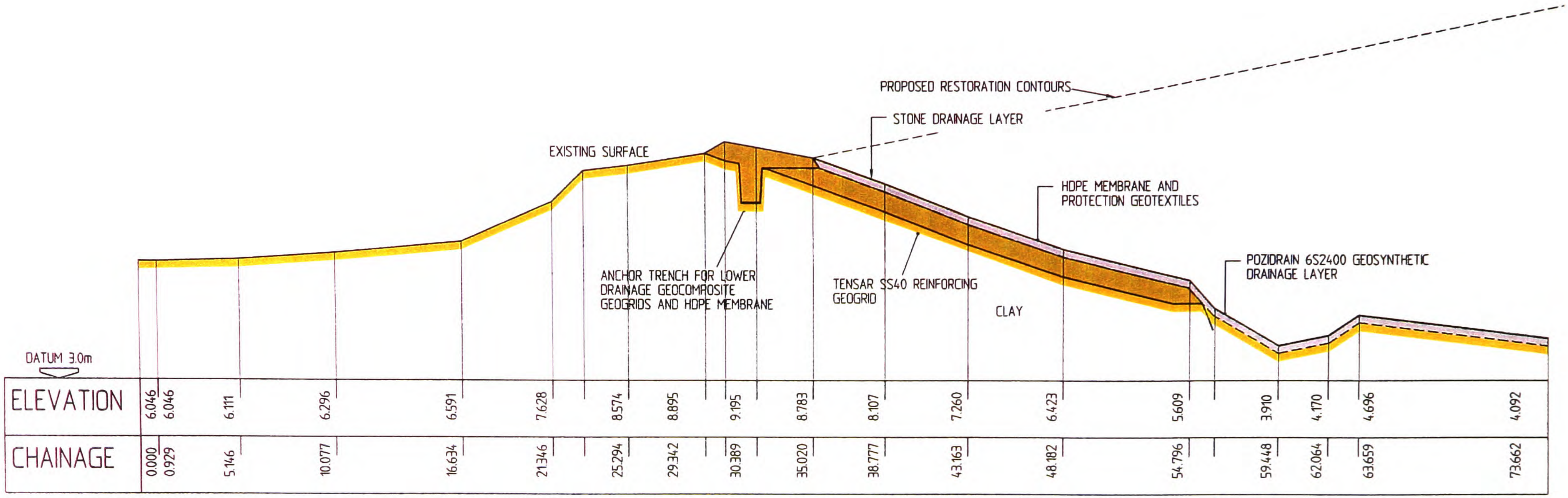
ENVIRONMENTAL PROTECTION DEPT.

• TITLE
SECTION A CURRENT
CONSTRUCTION DETAIL FOR
SEPARATION LAYER JAN. 1999

• DATE JAN '99
• SCALE AS SHOWN
• CAD REF. Fig4

PRODUCED BY AG
CHECKED
APPROVED

• DRAWING NUMBER
FIGURE 4



SECTION B

SCALE 1:200 HORZ
1:400 VERT

REV	DATE	BY	CHKD	• NOTES

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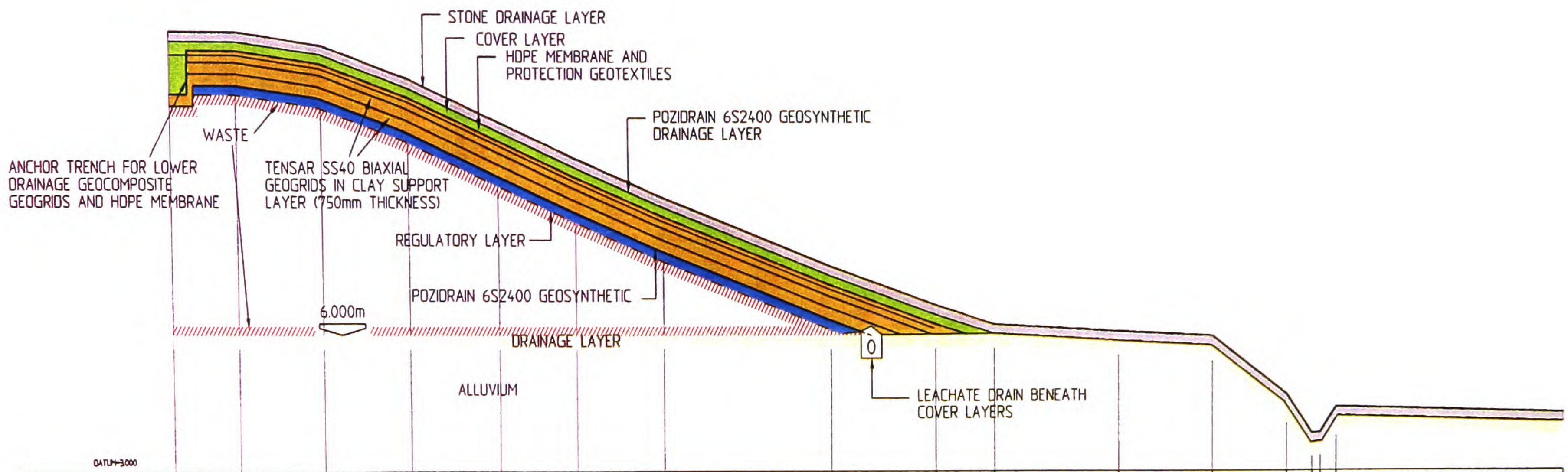
• CLIENT/PROJECT
ENVIRONMENTAL PROTECTION DEPT.

• TITLE
SECTION B CURRENT
CONSTRUCTION DETAIL FOR
SEPARATION LAYER JANUARY 1999

• DATE JAN '99 | PRODUCED BY AG
• SCALE AS SHOWN | CHECKED
• CAD REF. Fig5 | APPROVED

• DRAWING NUMBER
FIGURE 5



ELEVATION	12.579	12.306	11.584	10.646	9.851	8.996	7.497	6.643	6.224	6.067	5.967	3.820	4.405	4.262
CHAINAGE	2.831	6.463	10.234	14.129	17.479	21.280	28.623	33.224	35.806	41.309	45.447	49.837	50.892	60.874

SECTION E

SCALE 1:200 HORZ
1:100 VERT

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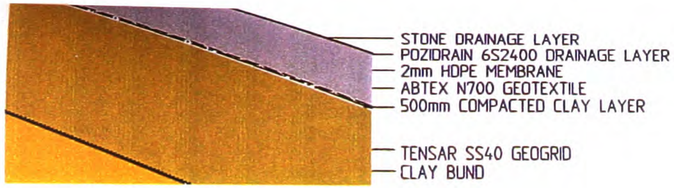
ENVIRONMENTAL PROTECTION DEPT.

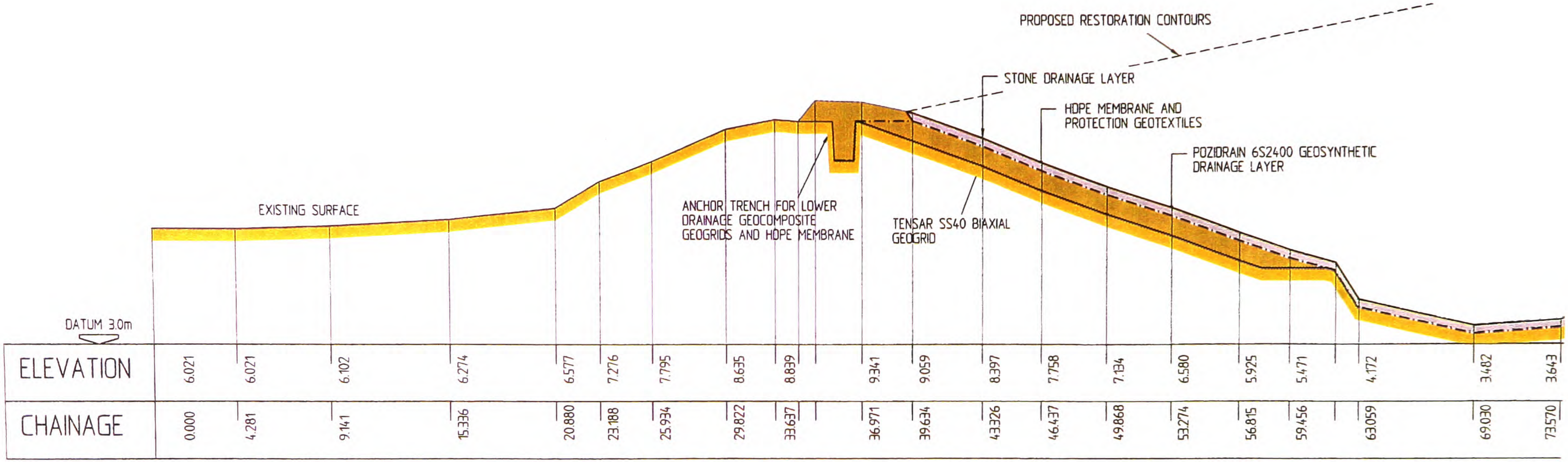
• TITLE
SECTION E CURRENT
CONSTRUCTION DETAIL FOR
SEPARATION LAYER JANUARY 1999

• DATE JAN '99 | PRODUCED BY AG
• SCALE AS SHOWN | CHECKED
• CAD REF. Fig6 | APPROVED

• DRAWING NUMBER
FIGURE 6



TYPICAL LAYERING DETAIL



SECTION F
SCALE 1:200 HORZ
1:400 VERT

REV	DATE	BY	CHKD	• NOTES

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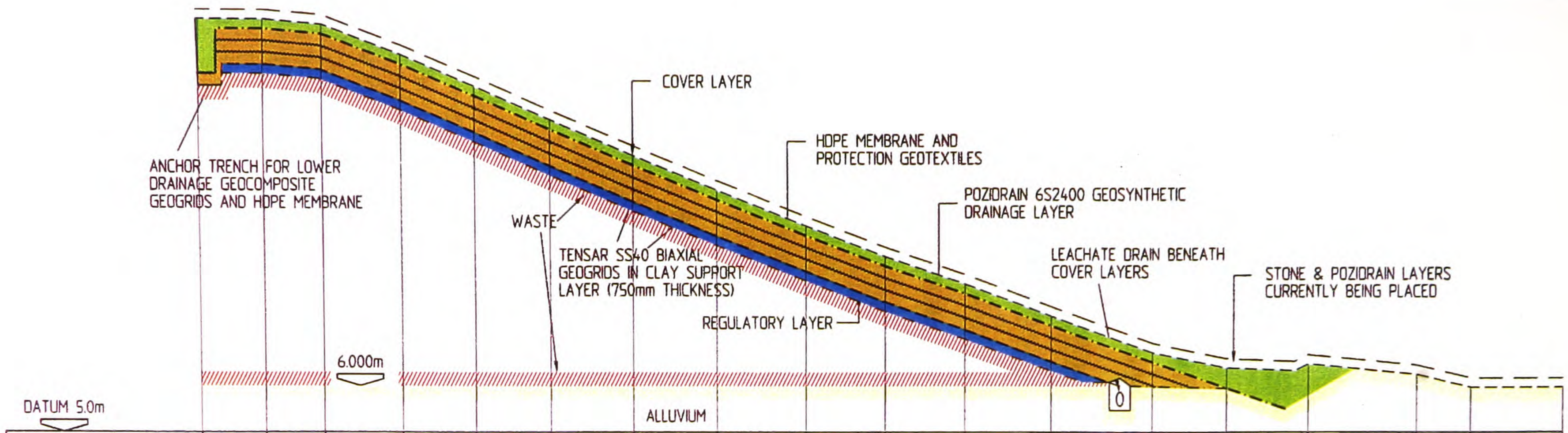
ENVIRONMENTAL PROTECTION DEPT.

• TITLE
SECTION F CURRENT
CONSTRUCTION DETAIL FOR
EASTERN BUND JANUARY 1999

• DATE JAN '99
PRODUCED BY AG
• SCALE AS SHOWN
CHECKED
• CAD REF. Fig7
APPROVED
• DRAWING NUMBER
FIGURE 7



ELEVATION	13.832	13.725	13.086	12.417	11.706	10.943	10.207	9.443	8.781	8.189	7.504	6.722	6.386	6.468	6.242	5.961	5.961
CHAINAGE	2.742	5.251	8.612	11.747	14.960	18.527	22.140	25.996	29.419	32.888	36.631	41.013	44.214	47.738	52.400	54.738	58.703

SECTION H

SCALE 1:200 HORZ
1:400 VERT

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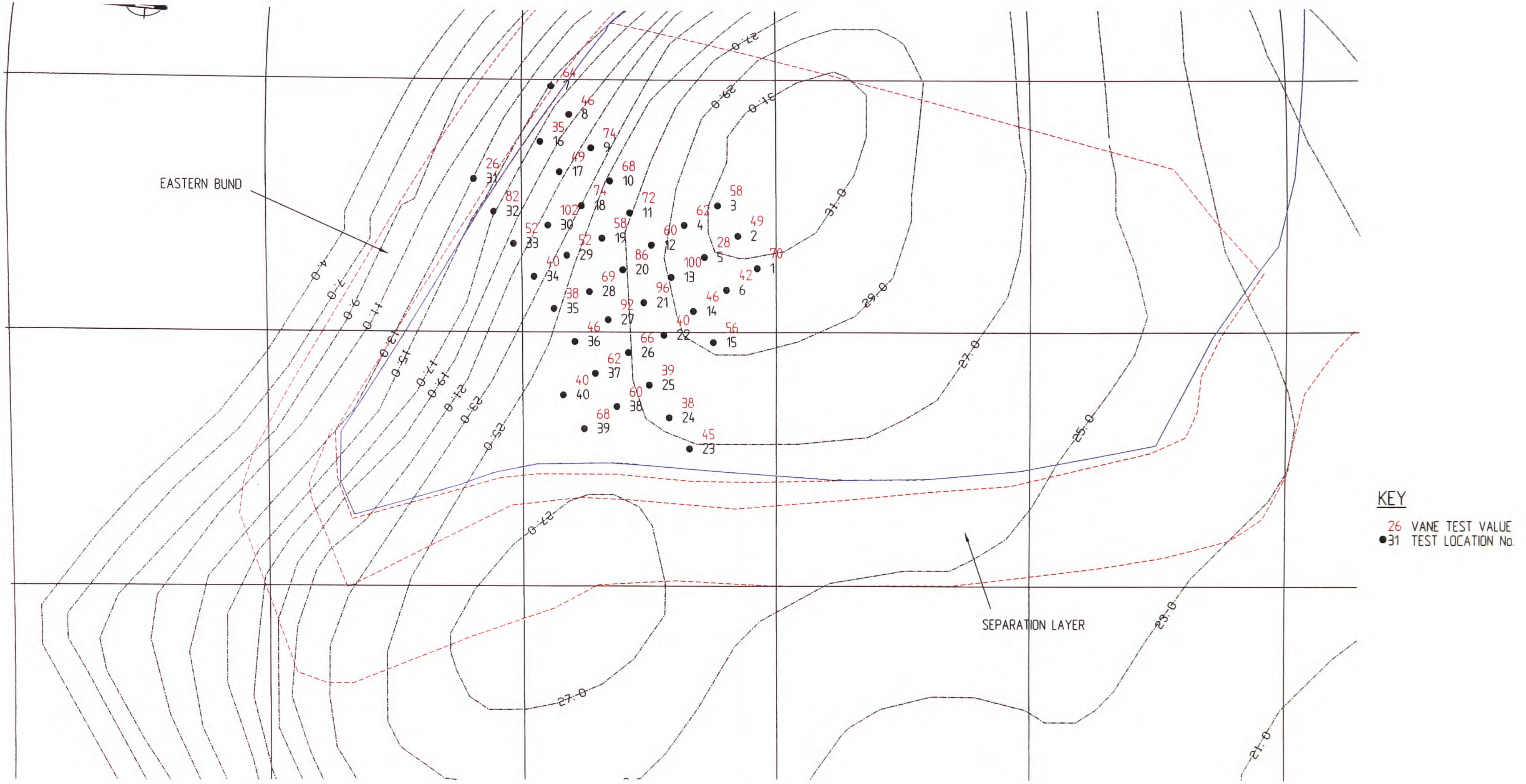
ENVIRONMENTAL PROTECTION DEPT.

• TITLE
SECTION H CURRENT CONSTRUCTION DETAIL FOR SEPARATION LAYER JANUARY 1999

• DATE JAN '99
• SCALE AS SHOWN
• CAD REF. Fig8
PRODUCED BY AG
CHECKED
APPROVED

• DRAWING NUMBER
FIGURE 8



REV	DATE	BY	CHKD

• NOTES
1. VANE TEST VALUES OF UNDRAINED SHEAR STRENGTH IN kN/m^2
2. TESTS CARRIED OUT ON CELL BASE AT 0.2m DEPTH (3.8m A.O.D.)

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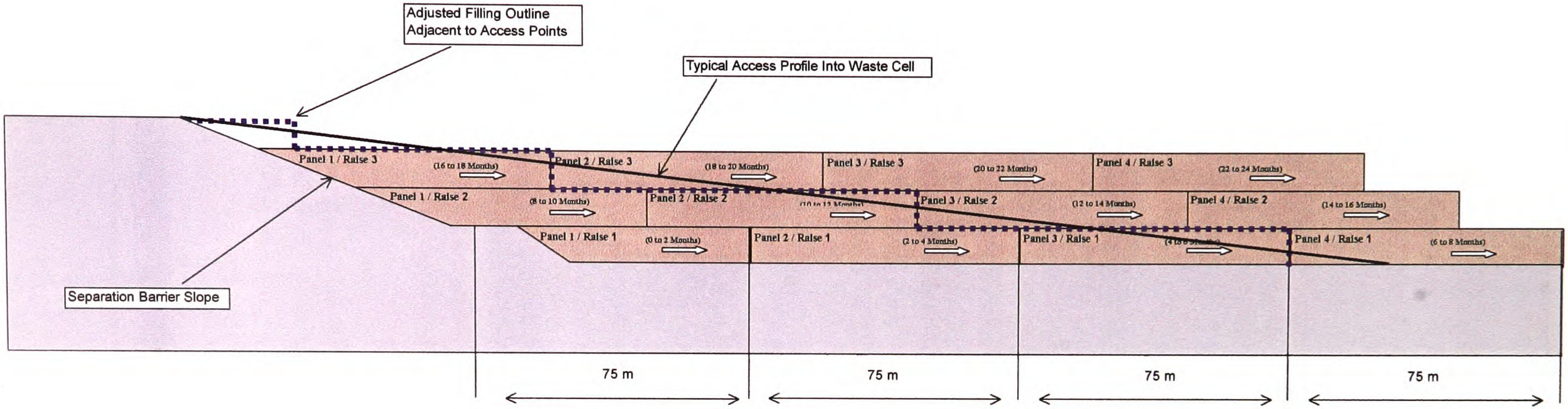
• TITLE
HAND VANE
LOCATION PLAN

• DATE MAR '99
• SCALE 1:1500
• CAD REF. FIG9
PRODUCED BY AG
CHECKED
APPROVED

• DRAWING NUMBER
BECCF026/ FIGURE 9

****** *** ****** EXTENSION - TYPICAL OPERATIONAL FILLING SEQUENCE



REV	DATE		BY	CHKD	NOTES
A	Apr-99	General revision description Typical Access Profile superimposed			General notes to go in this box

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Tel: (01222) 396045 Fax: (01222) 342779

CLIENT/PROJECT

****** ****** COUNCIL
****** **** LANDFILL
********* EXTENSION

TITLE

SCHEMATIC PHASING PLAN (With Typical Access Profile Superimposed).

DATE	MAR '99	PRODUCED BY	GJ
SCALE	NTS	CHECKED	KD
REF		APPROVED	KD

DRAWING NUMBER

BECCF***/ FIGURE 10

APPENDICES

APPENDIX 1 SEPARATION LAYER - ANALYSIS FOR CIRCULAR FAILURE

KENNEDY AND DONKIN LTD

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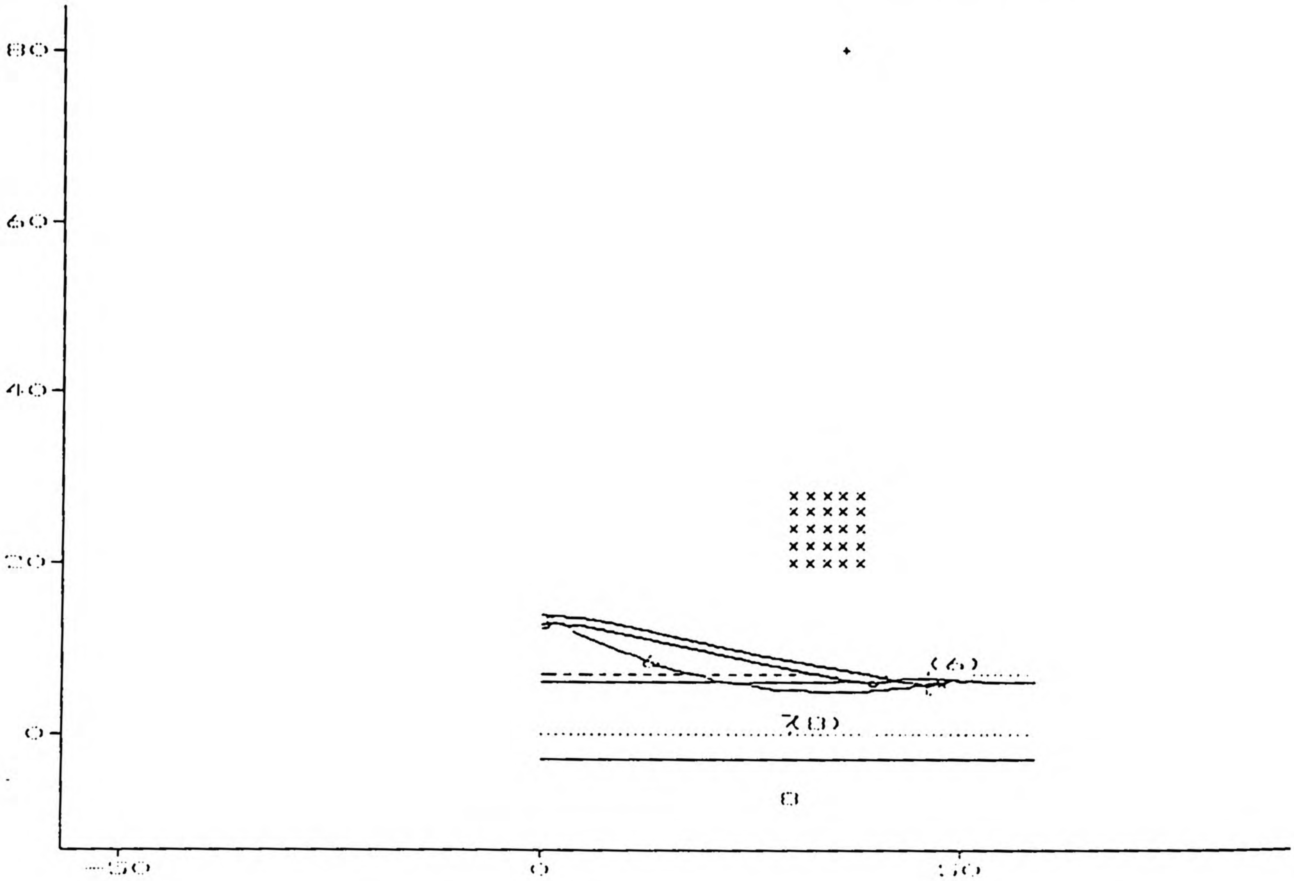
[redacted] Eastern Extension
Section H lower range lower leachate

| Sheet No. |
| Run No. HCLB |
| Job No. 026 |
| Made by : DJG |
| Date: 4-03-1999 |
| Checked : |

Units: KN,M



Scale = 1 : 889

---- Common point -----			----------- Critical circle ---------			
Point no.	X coord	Y coord	---- Centre ---- X	Y	Radius	Factor of safety
1	47.74	5.79	36.00	80.00	75.13	2.235

KENNEDY AND DONKIN LTD | Sheet No.
| Run No. HCLB

Program: SLOPE Version 9R.01 Revision A01.B01.R19
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| Made by : DJG
[redacted] Eastern Extension | Date: 4-03-1999
Section H lower range lower leachate | Checked :

Units: KN,M

INPUT DATA

PROFILE DATA

Grid line	1	2	3	4	5	6	7	8
X-Coord	0.00	0.75	0.77	1.00	1.02	2.74	5.25	8.61
Stratum	Y-Coordinates							
1(GL)	13.83	13.83	13.83	13.83	13.83	13.83	13.73	13.09
2	12.68	12.68	13.63	13.63	13.63	13.63	13.52	12.88
3	12.68	12.68	13.63	13.63	13.63	13.63	13.52	12.88
4	12.42	12.42	12.42	12.42	12.88	12.88	12.76	12.11
5	12.42	12.42	12.42	12.42	12.87	12.87	12.75	12.11
6	12.42	12.42	12.42	12.42	12.67	12.67	12.55	11.90
7	6.08	6.08	6.08	6.08	6.08	6.08	6.08	6.08
8	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00

Grid line	9	10	11	12	13	14	15	16
X-Coord	18.53	26.00	38.00	39.14	39.16	39.61	40.06	40.08
Stratum	Y-Coordinates							
1(GL)	10.94	9.44	7.26	7.05	7.05	6.97	6.89	6.89
2	10.74	9.24	7.06	6.85	6.85	6.77	6.69	6.69
3	10.74	9.24	7.06	6.85	6.85	6.77	6.69	6.68
4	9.97	8.47	6.29	6.09	6.09	6.18	6.00	6.00
5	9.96	8.47	6.29	6.08	5.47	5.47	5.47	6.00
6	9.76	8.26	6.08	6.08	5.47	5.47	5.47	5.99
7	6.08	6.08	6.08	6.08	5.47	5.47	5.47	5.99
8	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00

Grid line	17	18	19	20	21	22	23	24
X-Coord	41.01	44.21	46.72	46.74	47.74	49.74	52.40	54.74
Stratum	Y-Coordinates							
1(GL)	6.72	6.39	6.33	6.33	6.47	6.37	6.24	5.96
2	6.52	5.95	5.50	5.50	5.79	6.37	6.24	5.96
3	6.52	5.95	5.50	5.50	5.79	6.37	6.24	5.96
4	5.99	5.95	5.50	5.50	5.79	6.37	6.24	5.96
5	5.99	5.95	5.50	5.50	5.79	6.37	6.24	5.96
6	5.95	5.95	5.50	5.50	5.79	6.37	6.24	5.96
7	5.95	5.95	5.50	5.50	5.79	6.37	6.24	5.96
8	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00

Grid line	25
X-Coord	58.70
Stratum	Y-Coordinates
1(GL)	5.96
2	5.96
3	5.96
4	5.96
5	5.96
6	5.96
7	5.96
8	-3.00

SOIL PROPERTIES

--- Stratum ---		Bulk unit wt.		-------Strength parameters-------			
No.	Description	below GWL	above GWL	C	Phi (deg)	dC/dY	Datum for C
		KN/M3	KN/M3	KN/M2		KN/M2/M	
1	COVER	20.00	20.00	8.00	0.00		
2	HDPE	10.00	10.00	0.00	6.00		
3	CLAY	20.00	20.00	15.00	0.00		
4	POZIDRAIN 1	10.00	10.00	0.00	6.00		
5	REGULATION LAYER	20.00	18.00	30.00	0.00		
6	WASTE	15.00	15.00	0.00	20.00	Piezometric surface 1	
7	ALLUVIUM	18.00	18.00	6.00	0.00	13.00	6.08
8	GRAVEL	20.00	20.00	0.00	30.00	Piezometric surface 4	

GROUND WATER CONDITIONS

Unit wt. of water = 9.81 KN/M3

Grid line	1	2	3	4	5	6	7	8
X-Coord	0.00	0.75	0.77	1.00	1.02	2.74	5.25	8.61
Ground water level	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00

Grid line	9	10	11	12	13	14	15	16
X-Coord	18.53	26.00	38.00	39.14	39.16	39.61	40.06	40.08
Ground water level	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00

Grid line	17	18	19	20	21	22	23	24
X-Coord	41.01	44.21	46.72	46.74	47.74	49.74	52.40	54.74
Ground water level	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00

Grid line	25
X-Coord	58.70
Ground water level	6.00

Piezometric surfaces associated with individual strata

Grid line	1	2	3	4	5	6	7	8
X-Coord	0.00	0.75	0.77	1.00	1.02	2.74	5.25	8.61
Surface	Piezometric elevation							
1	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Grid line	9	10	11	12	13	14	15	16
X-Coord	18.53	26.00	38.00	39.14	39.16	39.61	40.06	40.08
Surface	Piezometric elevation							
1	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Grid line	17	18	19	20	21	22	23	24
X-Coord	41.01	44.21	46.72	46.74	47.74	49.74	52.40	54.74
Surface	Piezometric elevation							
1	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Piezometric surfaces (continued)

Grid line 25
X-Coord 58.70

Surface	Piezometric elevation
1	7.00
4	0.00

CIRCULAR SLIP SURFACE DATA

Grid of centres:	X	Y
Corner of grid	30.00	20.00
Grid increment	2.00	2.00
No. of grid lines	5	5

The grid of centres will be extended automatically until a minimum factor of safety has been found.

Common point(s):	X	Y
Coordinates of (first) point	47.74	5.79

Number of points = 1

ANALYSIS OPTIONS

Method of analysis: BISHOP - Simplified : Horizontal interslice forces

Factors of safety calculated on Soil Strength

Partial factor of safety on tan(phi) = 1.000
Partial factor of safety on drained cohesion = 1.000
Partial factor of safety on undrained cohesion = 1.000
Partial factor of safety on soil weight = 1.000
Partial factor of safety on surcharge loads = 1.000
Minimum number of slices = 10

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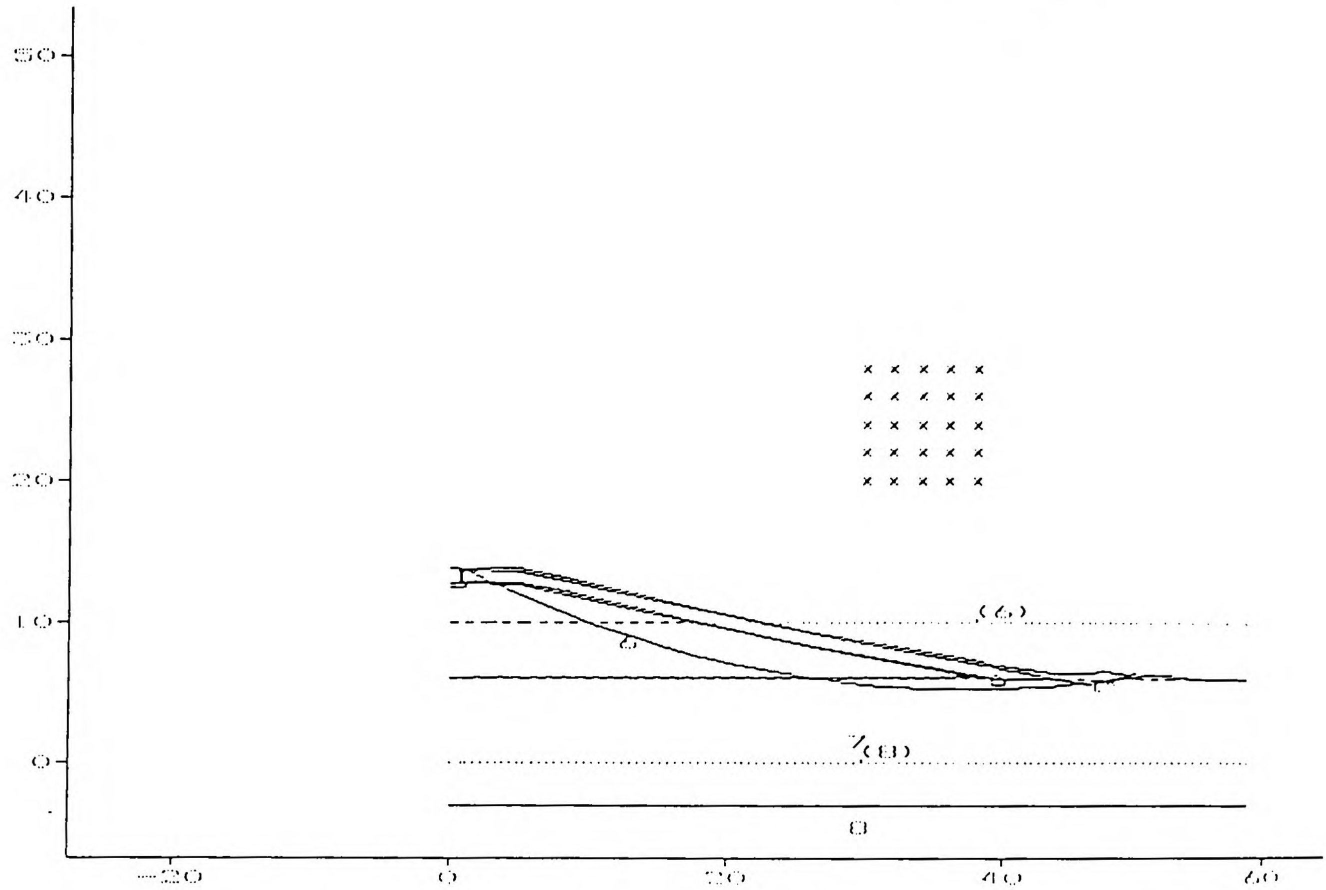
[redacted] Eastern Extension
Section H separation lower range high leachate

Sheet No.	
Run No.	HCLB1
Job No.	025
Made by :	DJG
Date:	4-03-1999
Checked :	

Units: KN,M



Scale = 1 : 541

---- Common point -----			----------- Critical circle ---------			
Point	X	Y	---- Centre ----		Radius	Factor of
no.	coord	coord	X	Y		safety
1	47.74	5.79	38.00	90.00	84.77	1.872

KENNEDY AND DONKIN LTD | Sheet No.
| Run No. HCL31

Program: SLOPE Version 9R.01 Revision A01.B01.R19
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| Made by : DJG
[redacted] Eastern Extension | Date: 4-03-1999
Section H separation lower range high leachate | Checked :

Units: KN,M

INPUT DATA

PROFILE DATA

Grid line	1	2	3	4	5	6	7	8
X-Coord	0.00	0.75	0.77	1.00	1.02	2.74	5.25	8.61
Stratum	Y-Coordinates							
1(GL)	13.83	13.83	13.83	13.83	13.83	13.83	13.73	13.09
2	12.68	12.68	13.63	13.63	13.63	13.63	13.52	12.88
3	12.68	12.68	13.63	13.63	13.63	13.63	13.52	12.88
4	12.42	12.42	12.42	12.42	12.88	12.88	12.76	12.11
5	12.42	12.42	12.42	12.42	12.87	12.87	12.75	12.11
6	12.42	12.42	12.42	12.42	12.67	12.67	12.55	11.90
7	6.08	6.08	6.08	6.08	6.08	6.08	6.08	6.08
8	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00

Grid line	9	10	11	12	13	14	15	16
X-Coord	18.53	26.00	38.00	39.14	39.16	39.61	40.06	40.08
Stratum	Y-Coordinates							
1(GL)	10.94	9.44	7.26	7.05	7.05	6.97	6.89	6.89
2	10.74	9.24	7.06	6.85	6.85	6.77	6.69	6.69
3	10.74	9.24	7.06	6.85	6.85	6.77	6.69	6.68
4	9.97	8.47	6.29	6.09	6.09	6.18	6.00	6.00
5	9.96	8.47	6.29	6.08	5.47	5.47	5.47	6.00
6	9.76	8.26	6.08	6.08	5.47	5.47	5.47	5.99
7	6.08	6.08	6.08	6.08	5.47	5.47	5.47	5.99
8	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00

Grid line	17	18	19	20	21	22	23	24
X-Coord	41.01	44.21	46.72	46.74	47.74	49.74	52.40	54.74
Stratum	Y-Coordinates							
1(GL)	6.72	6.39	6.33	6.33	6.47	6.37	6.24	5.96
2	6.52	5.95	5.50	5.50	5.79	6.37	6.24	5.96
3	6.52	5.95	5.50	5.50	5.79	6.37	6.24	5.96
4	5.99	5.95	5.50	5.50	5.79	6.37	6.24	5.96
5	5.99	5.95	5.50	5.50	5.79	6.37	6.24	5.96
6	5.95	5.95	5.50	5.50	5.79	6.37	6.24	5.96
7	5.95	5.95	5.50	5.50	5.79	6.37	6.24	5.96
8	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00

Grid line	25
X-Coord	58.70
Stratum	Y-Coordinates
1(GL)	5.96
2	5.96
3	5.96
4	5.96
5	5.96
6	5.96
7	5.96
8	-3.00

SOIL PROPERTIES

--- Stratum --- No.	Description	Bulk unit wt. below GWL KN/M3	Bulk unit wt. above GWL KN/M3	Strength parameters C KN/M2	Phi (deg)	dC/dY KN/M2/M	Datum for C
1	COVER	20.00	20.00	8.00	0.00		
2	HDPE	10.00	10.00	0.00	6.00		
3	CLAY	20.00	20.00	15.00	0.00		
4	POZIDRAIN 1	10.00	10.00	0.00	6.00		
5	REGULATION LAYER	20.00	18.00	30.00	0.00		
6	WASTE	15.00	15.00	0.00	20.00	Piezometric surface 1	
7	ALLUVIUM	18.00	18.00	6.00	0.00	13.00	6.08
8	GRAVEL	20.00	20.00	0.00	30.00	Piezometric surface 4	

GROUND WATER CONDITIONS

Unit wt. of water = 9.81 KN/M3

Grid line	1	2	3	4	5	6	7	8
X-Coord	0.00	0.75	0.77	1.00	1.02	2.74	5.25	8.61
Ground water level	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00

Grid line	9	10	11	12	13	14	15	16
X-Coord	18.53	26.00	38.00	39.14	39.16	39.61	40.06	40.08
Ground water level	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00

Grid line	17	18	19	20	21	22	23	24
X-Coord	41.01	44.21	46.72	46.74	47.74	49.74	52.40	54.74
Ground water level	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00

Grid line	25
X-Coord	58.70
Ground water level	6.00

Piezometric surfaces associated with individual strata

Grid line	1	2	3	4	5	6	7	8
X-Coord	0.00	0.75	0.77	1.00	1.02	2.74	5.25	8.61
Surface	Piezometric elevation							
1	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Grid line	9	10	11	12	13	14	15	16
X-Coord	18.53	26.00	38.00	39.14	39.16	39.61	40.06	40.08
Surface	Piezometric elevation							
1	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Grid line	17	18	19	20	21	22	23	24
X-Coord	41.01	44.21	46.72	46.74	47.74	49.74	52.40	54.74
Surface	Piezometric elevation							
1	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Piezometric surfaces (continued)

```
Grid line  25
X-Coord   58.70
---------------
Surface    Piezometric elevation
   1       10.00
   4        0.00
```

CIRCULAR SLIP SURFACE DATA

```
 Grid of centres:                    X         Y
 Corner of grid                    30.00     20.00
 Grid increment                     2.00      2.00
 No. of grid lines                  5         5
 The grid of centres will be extended automatically
 until a minimum factor of safety has been found.

 Common point(s):                          X         Y
 Coordinates of (first) point          47.74      5.79
 Number of points = 1
```

ANALYSIS OPTIONS

```
 Method of analysis: BISHOP - Simplified : Horizontal interslice forces
  Factors of safety calculated on Soil Strength
  Partial factor of safety on tan(phi)             = 1.000
  Partial factor of safety on drained cohesion     = 1.000
  Partial factor of safety on undrained cohesion = 1.000
  Partial factor of safety on soil weight          = 1.000
  Partial factor of safety on surcharge loads      = 1.000
  Minimum number of slices = 10
```

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Program: SLOPE Version 9R.01 Revision A01.B01.R19
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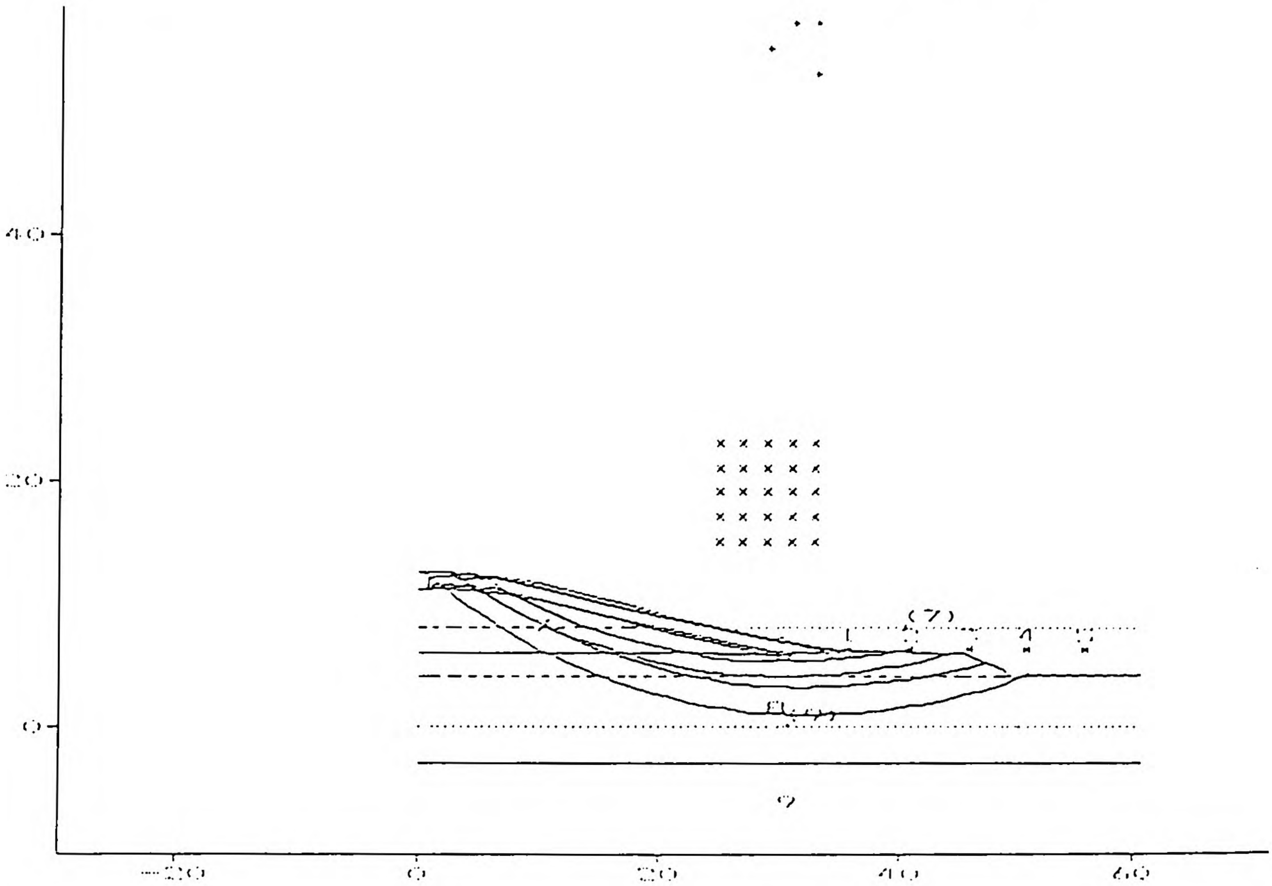
[redacted] Eastern Extension
Section E separation layer lower range

Sheet No.	
Run No.	EC2LB
Job No.	026
Made by :	DJC
Date: 4-03-1999	
Checked :	

Units: KN,M



Scale = 1 : 621

---- Common point -----			---------- Critical circle ---------			
Point no.	X coord	Y coord	---- Centre ---- X	Y	Radius	Factor of safety
1	35.81	6.22	29.00	55.00	49.25	1.680
2	40.81	6.22	31.00	57.00	51.72	1.947
3	45.81	6.22	31.00	57.00	52.90	2.601
4	50.81	6.22	33.00	57.00	53.31	3.143
5	55.81	6.22	33.00	53.00	52.04	3.651

KENNEDY AND DONKIN LTD

Program: SLOPE Version 9R.01 Revision A01.301.R19
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[redacted] Eastern Extension
Section E separation layer lower range

Sheet No.	
Run No.	EC2LB
Job No.	026
Made by :	DJG
Date:	4-03-1999
Checked :	

Units: KN,M

INPUT DATA

PROFILE DATA

Grid line	1	2	3	4	5	6	7	8
X-Coord	0.00	0.75	0.77	1.00	1.02	2.83	6.46	10.23
Stratum	Y-Coordinates							
1(GL)	12.58	12.58	12.58	12.58	12.58	12.58	12.31	11.58
2	12.37	12.37	12.37	12.37	12.37	12.37	12.09	11.37
3	11.22	11.22	12.17	12.17	12.17	12.17	11.89	11.17
4	11.22	11.22	12.17	12.17	12.17	12.17	11.89	11.16
5	10.97	10.97	10.97	10.97	11.42	11.42	11.13	10.39
6	10.96	10.96	10.96	10.96	11.42	11.41	11.12	10.39
7	10.96	10.96	10.96	10.96	11.22	11.21	10.92	10.18
8	6.03	6.03	6.03	6.03	6.03	6.03	6.03	6.03
9	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00

Grid line	9	10	11	12	13	14	15	16
X-Coord	17.48	21.28	29.07	29.93	29.95	30.40	30.85	30.87
Stratum	Y-Coordinates							
1(GL)	9.85	9.00	7.41	7.26	7.25	7.17	7.09	7.08
2	9.64	8.78	7.20	7.04	7.03	6.95	6.87	6.87
3	9.44	8.58	7.00	6.84	6.84	6.75	6.67	6.67
4	9.43	8.58	7.00	6.84	6.84	6.75	6.67	6.67
5	8.66	7.81	6.24	6.08	6.07	6.19	6.00	6.00
6	8.65	7.81	6.23	6.07	5.49	5.49	5.49	6.00
7	8.45	7.60	6.03	6.07	5.49	5.49	5.49	6.00
8	6.03	6.03	6.03	6.07	5.49	5.49	5.49	6.00
9	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00

Grid line	17	18	19	20	21	22	23	24
X-Coord	33.40	34.55	35.81	45.45	48.71	49.84	50.20	50.89
Stratum	Y-Coordinates							
1(GL)	6.63	6.42	6.22	5.97	4.69	3.82	3.84	4.41
2	6.42	6.22	6.22	5.97	4.69	3.82	3.84	4.41
3	6.22	5.72	6.22	5.97	4.69	3.82	3.84	4.41
4	6.22	5.72	6.22	5.97	4.69	3.82	3.84	4.41
5	6.22	5.72	6.22	5.97	4.69	3.82	3.84	4.41
6	6.22	5.72	6.22	5.97	4.69	3.82	3.84	4.41
7	6.22	5.72	6.22	5.97	4.69	3.82	3.84	4.41
8	6.22	5.72	6.22	5.97	4.69	3.82	3.84	4.41
9	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00

PROFILE DATA (continued)

Grid line 25
X-Coord 60.87

Stratum	Y-Coordinates
1(GL)	4.26
2	4.26
3	4.26
4	4.26
5	4.26
6	4.26
7	4.26
8	4.26
9	-3.00

SOIL PROPERTIES

--- Stratum --- No.	Description	Bulk unit wt. below GWL KN/M3	Bulk unit wt. above GWL KN/M3	Strength parameters C KN/M2	Phi (deg)	dC/dY KN/M2/M	Datum for C
1	DRAINAGE STONE	20.00	20.00	0.00	16.00		
2	COVER	20.00	20.00	8.00	0.00		
3	HDPE	20.00	20.00	0.00	6.00		
4	CLAY	20.00	20.00	15.00	0.00		
5	POZIDRAIN 2	20.00	20.00	0.00	6.00		
6	REGULATION LAYER	15.00	15.00	0.00	20.00		
7	WASTE	15.00	15.00	0.00	20.00	Piezometric surface 1	
8	ALLUVIUM	18.00	18.00	6.00	0.00	13.00	6.00
9	GRAVEL	20.00	20.00	0.00	30.00	Piezometric surface 4	

GROUND WATER CONDITIONS

Unit wt. of water = 9.81 KN/M3

Grid line	1	2	3	4	5	6	7	8
X-Coord	0.00	0.75	0.77	1.00	1.02	2.83	6.46	10.23
Ground water level	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00

Grid line	9	10	11	12	13	14	15	16
X-Coord	17.48	21.28	29.07	29.93	29.95	30.40	30.85	30.87
Ground water level	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00

Grid line	17	18	19	20	21	22	23	24
X-Coord	33.40	34.55	35.81	45.45	48.71	49.34	50.20	50.89
Ground water level	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00

Grid line	25
X-Coord	60.87
Ground water level	4.00

Piezometric surfaces associated with individual strata

Grid line	1	2	3	4	5	6	7	8
X-Coord	0.00	0.75	0.77	1.00	1.02	2.33	5.46	10.23
Surface	Piezometric elevation							
1	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Grid line	9	10	11	12	13	14	15	16
X-Coord	17.48	21.28	29.07	29.93	29.95	30.40	30.85	30.37
Surface	Piezometric elevation							
1	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Grid line	17	18	19	20	21	22	23	24
X-Coord	33.40	34.55	35.81	45.45	48.71	49.84	50.20	50.39
Surface	Piezometric elevation							
1	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Grid line	25
X-Coord	60.87
Surface	Piezometric elevation
1	8.00
4	0.00

CIRCULAR SLIP SURFACE DATA

Grid of centres:	X	Y
Corner of grid	25.00	15.00
Grid increment	2.00	2.00
No. of grid lines	5	5

The grid of centres will be extended automatically until a minimum factor of safety has been found.

Common point(s):	X	Y
Coordinates of (first) point	35.81	6.22
Increment between points	5.00	0.00

Number of points = 5

ANALYSIS OPTIONS

Method of analysis: BISHOP - Simplified : Horizontal interslice forces

Factors of safety calculated on Soil Strength

Partial factor of safety on tan(phi) = 1.000

Partial factor of safety on drained cohesion = 1.000

Partial factor of safety on undrained cohesion = 1.000

Partial factor of safety on soil weight = 1.000

Partial factor of safety on surcharge loads = 1.000

Minimum number of slices = 10

KENNEDY AND DONKIN LTD

Program: SLOPE Version 9R.01 Revision A01.B01.R19
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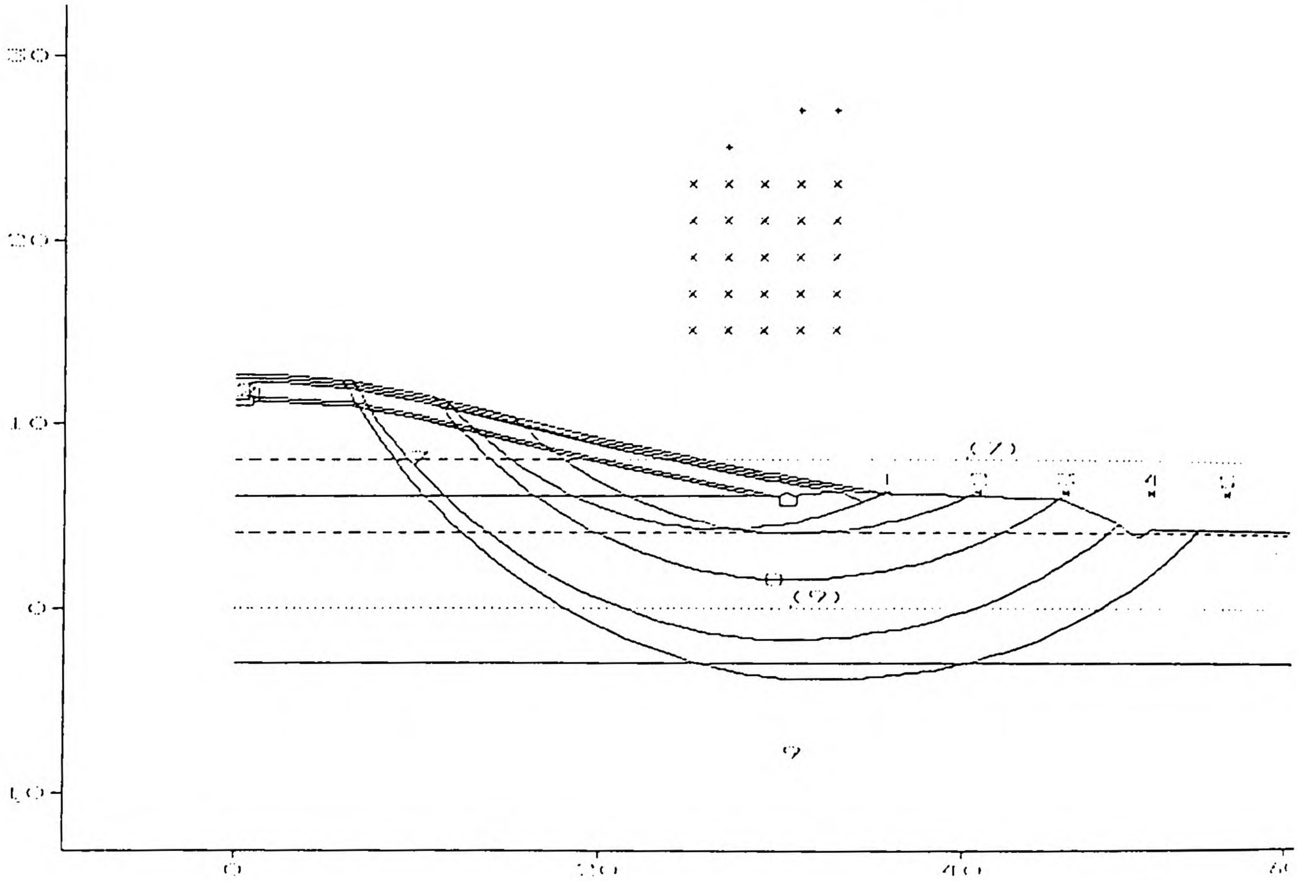
[redacted] Eastern Extension
Section E Separation Layer upper range parameters

| Sheet No.
| Run No. EC2UB
|
| Job No. 026
| Made by : DJG
| Date: 4-03-1999
| Checked :

Units: KN,M



Scale = 1 : 412

---- Common point -----			---------- Critical circle ---------			
Point no.	X coord	Y coord	---- Centre ---- X	Y	Radius	Factor of safety
1	35.81	6.22	27.00	25.00	20.74	3.047
2	40.81	6.22	31.00	27.00	22.93	3.834
3	45.81	6.22	31.00	27.00	25.52	5.360
4	50.81	6.22	31.00	27.00	28.71	6.195
5	55.81	6.22	33.00	27.00	30.86	6.915

KENNEDY AND DONKIN LTD

Program: SLOPE Version 9R.01 Revision A01.B01.R19
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[redacted] Eastern Extension
Section E Separation Layer upper range parameters

| Sheet No.
| Run No. EC2UB
|
| Job No. 026
| Made by : DJG
| Date: 4-03-1999
| Checked :

Units: KN,M

INPUT DATA

PROFILE DATA

Grid line	1	2	3	4	5	6	7	8
X-Coord	0.00	0.75	0.77	1.00	1.02	2.83	6.46	10.23
Stratum	Y-Coordinates							
1(GL)	12.58	12.58	12.58	12.58	12.58	12.58	12.31	11.58
2	12.37	12.37	12.37	12.37	12.37	12.37	12.09	11.37
3	11.22	11.22	12.17	12.17	12.17	12.17	11.89	11.17
4	11.22	11.22	12.17	12.17	12.17	12.17	11.89	11.16
5	10.97	10.97	10.97	10.97	11.42	11.42	11.13	10.39
6	10.96	10.96	10.96	10.96	11.42	11.41	11.12	10.39
7	10.96	10.96	10.96	10.96	11.22	11.21	10.92	10.18
8	6.03	6.03	6.03	6.03	6.03	6.03	6.03	6.03
9	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00

Grid line	9	10	11	12	13	14	15	16
X-Coord	17.48	21.28	29.07	29.93	29.95	30.40	30.85	30.87
Stratum	Y-Coordinates							
1(GL)	9.85	9.00	7.41	7.26	7.25	7.17	7.09	7.08
2	9.64	8.78	7.20	7.04	7.03	6.95	6.87	6.87
3	9.44	8.58	7.00	6.84	6.84	6.75	6.67	6.67
4	9.43	8.58	7.00	6.84	6.84	6.75	6.67	6.67
5	8.66	7.81	6.24	6.08	6.07	6.19	6.00	6.00
6	8.66	7.81	6.23	6.07	5.49	5.49	5.49	6.00
7	8.45	7.60	6.03	6.07	5.49	5.49	5.49	6.00
8	6.03	6.03	6.03	6.07	5.49	5.49	5.49	6.00
9	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00

Grid line	17	18	19	20	21	22	23	24
X-Coord	33.40	34.55	35.81	45.45	48.71	49.84	50.20	50.89
Stratum	Y-Coordinates							
1(GL)	6.63	6.42	6.22	5.97	4.69	3.82	3.84	4.41
2	6.42	6.22	6.22	5.97	4.69	3.82	3.84	4.41
3	6.22	5.72	6.22	5.97	4.69	3.82	3.84	4.41
4	6.22	5.72	6.22	5.97	4.69	3.82	3.84	4.41
5	6.22	5.72	6.22	5.97	4.69	3.82	3.84	4.41
6	6.22	5.72	6.22	5.97	4.69	3.82	3.84	4.41
7	6.22	5.72	6.22	5.97	4.69	3.82	3.84	4.41
8	6.22	5.72	6.22	5.97	4.69	3.82	3.84	4.41
9	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00

PROFILE DATA (continued)

Grid line 25
X-Coord 60.87

Stratum	Y-Coordinates
1(GL)	4.26
2	4.26
3	4.26
4	4.26
5	4.26
6	4.26
7	4.26
8	4.26
9	-3.00

SOIL PROPERTIES

--- Stratum --- No.	Description	Bulk unit wt. below GWL KN/M3	above GWL KN/M3	-------Strength parameters------- C KN/M2	Phi (deg)	dC/dY KN/M2/M	Datum for C
1	DRAINAGE STONE	18.00	18.00	0.00	33.00		
2	COVER	18.00	18.00	25.00	0.00		
3	HDPE	20.00	20.00	0.00	8.00		
4	CLAY	18.00	18.00	25.00	0.00		
5	POZIDRAIN 2	20.00	20.00	0.00	8.00		
6	REGULATION LAYER	11.00	11.00	0.00	27.00		
7	WASTE	11.00	11.00	0.00	27.00	Piezometric surface 1	
8	ALLUVIUM	18.00	18.00	6.00	0.00	13.00	6.00
9	GRAVEL	20.00	20.00	0.00	45.00	Piezometric surface 4	

GROUND WATER CONDITIONS

Unit wt. of water = 9.81 KN/M3

Grid line	1	2	3	4	5	6	7	8
X-Coord	0.00	0.75	0.77	1.00	1.02	2.83	6.46	10.23
Ground water level	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00

Grid line	9	10	11	12	13	14	15	16
X-Coord	17.48	21.28	29.07	29.93	29.95	30.40	30.85	30.87
Ground water level	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00

Grid line	17	18	19	20	21	22	23	24
X-Coord	33.40	34.55	35.81	45.45	48.71	49.84	50.20	50.89
Ground water level	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00

Grid line	25
X-Coord	60.87
Ground water level	4.00

Piezometric surfaces associated with individual strata

Grid line	1	2	3	4	5	6	7	8
X-Coord	0.00	0.75	0.77	1.00	1.02	2.83	6.46	10.23
Surface	Piezometric elevation							
1	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Grid line	9	10	11	12	13	14	15	16
X-Coord	17.48	21.28	29.07	29.93	29.95	30.40	30.85	30.87
Surface	Piezometric elevation							
1	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Grid line	17	18	19	20	21	22	23	24
X-Coord	33.40	34.55	35.81	45.45	48.71	49.84	50.20	50.89
Surface	Piezometric elevation							
1	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Grid line	25
X-Coord	60.87
Surface	Piezometric elevation
1	8.00
4	0.00

CIRCULAR SLIP SURFACE DATA

Grid of centres:	X	Y
Corner of grid	25.00	15.00
Grid increment	2.00	2.00
No. of grid lines	5	5

The grid of centres will be extended automatically
until a minimum factor of safety has been found.

Common point(s):	X	Y
Coordinates of (first) point	35.81	6.22
Increment between points	5.00	0.00

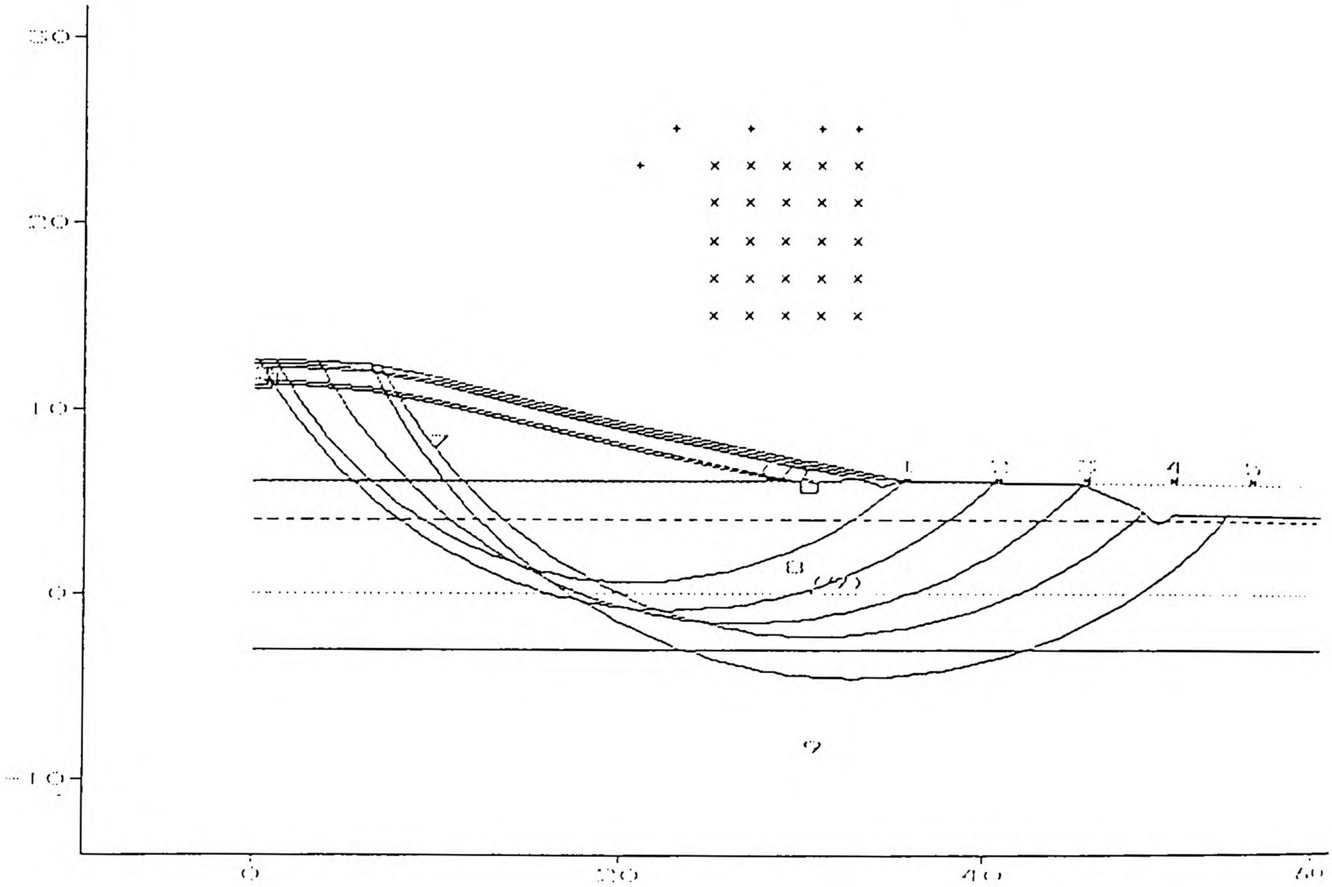
Number of points = 5

ANALYSIS OPTIONS

Method of analysis: BISHOP - Simplified : Horizontal interslice forces
Factors of safety calculated on Soil Strength
Partial factor of safety on tan(phi) = 1.000
Partial factor of safety on drained cohesion = 1.000
Partial factor of safety on undrained cohesion = 1.000
Partial factor of safety on soil weight = 1.000
Partial factor of safety on surcharge loads = 1.000
Minimum number of slices = 10

KENNEDY AND DONKIN LTD	Sheet No.
	Run No. EC2
Program: SLOPE Version 9R.01 Revision A01.B01.R19	
Licensed from GEOSOLVE	Job No. 025
	Made by : DJG
[redacted] Eastern Extension	Date: 4-03-1999
Section E separation GWP parameters	Checked :

Units: KN,M



Scale = 1 : 412

---- Common point -----			---------- Critical circle --------			
Point no.	X coord	Y coord	---- Centre ---- X	Y	Radius	Factor of safety
1	35.81	6.22	21.00	23.00	22.38	1.603
2	40.81	6.22	23.00	25.00	25.83	1.631
3	45.81	6.22	27.00	25.00	26.58	1.730
4	50.81	6.22	31.00	25.00	27.30	1.732
5	55.81	6.22	33.00	25.00	29.55	3.391

KENNEDY AND DONKIN LTD

Program: SLOPE Version 9R.01 Revision A01.B01.R19
Licensed from GEOSOLVE

[redacted] Eastern Extension
Section E separation GWP parameters

Sheet No.	
Run No.	EC2
Job No.	026
Made by :	DJG
Date:	4-03-1999
Checked :	

Units: KN,M

INPUT DATA

PROFILE DATA

Grid line	1	2	3	4	5	6	7	8
X-Coord	0.00	0.75	0.77	1.00	1.02	2.83	6.46	10.23
Stratum	Y-Coordinates							
1(GL)	12.58	12.58	12.58	12.58	12.58	12.58	12.31	11.58
2	12.37	12.37	12.37	12.37	12.37	12.37	12.09	11.37
3	11.22	11.22	12.17	12.17	12.17	12.17	11.89	11.17
4	11.22	11.22	12.17	12.17	12.17	12.17	11.89	11.16
5	10.97	10.97	10.97	10.97	11.42	11.42	11.13	10.39
6	10.96	10.96	10.96	10.96	11.42	11.41	11.12	10.39
7	10.96	10.96	10.96	10.96	11.22	11.21	10.92	10.18
8	6.03	6.03	6.03	6.03	6.03	6.03	6.03	6.03
9	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00

Grid line	9	10	11	12	13	14	15	16
X-Coord	17.48	21.28	29.07	29.93	29.95	30.40	30.85	30.87
Stratum	Y-Coordinates							
1(GL)	9.85	9.00	7.41	7.26	7.25	7.17	7.09	7.08
2	9.64	8.78	7.20	7.04	7.03	6.95	6.87	6.87
3	9.44	8.58	7.00	6.84	6.84	6.75	6.67	6.67
4	9.43	8.58	7.00	6.84	6.84	6.75	6.67	6.67
5	8.66	7.81	6.24	6.08	6.07	6.19	6.00	6.00
6	8.65	7.81	6.23	6.07	5.49	5.49	5.49	6.00
7	8.45	7.60	6.03	6.07	5.49	5.49	5.49	6.00
8	6.03	6.03	6.03	6.07	5.49	5.49	5.49	6.00
9	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00

Grid line	17	18	19	20	21	22	23	24
X-Coord	33.40	34.55	35.81	45.45	48.71	49.84	50.20	50.89
Stratum	Y-Coordinates							
1(GL)	6.63	6.42	6.22	5.97	4.69	3.82	3.84	4.41
2	6.42	6.22	6.22	5.97	4.69	3.82	3.84	4.41
3	6.22	5.72	6.22	5.97	4.69	3.82	3.84	4.41
4	6.22	5.72	6.22	5.97	4.69	3.82	3.84	4.41
5	6.22	5.72	6.22	5.97	4.69	3.82	3.84	4.41
6	6.22	5.72	6.22	5.97	4.69	3.82	3.84	4.41
7	6.22	5.72	6.22	5.97	4.69	3.82	3.84	4.41
8	6.22	5.72	6.22	5.97	4.69	3.82	3.84	4.41
9	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00

PROFILE DATA (continued)

Grid line 25
X-Coord 60.87

Stratum	Y-Coordinates
1(GL)	4.26
2	4.26
3	4.26
4	4.26
5	4.26
6	4.26
7	4.26
8	4.26
9	-3.00

SOIL PROPERTIES

--- Stratum --- No.	Description	Bulk unit wt. below GWL KN/M3	Bulk unit wt. above GWL KN/M3	-------Strength parameters------- C KN/M2	Phi (deg)	dC/dY KN/M2/M	Datum for C
1	DRAINAGE STONE	20.00	20.00	0.00	16.00		
2	COVER	20.00	20.00	0.00	16.00		
3	HDPE	20.00	20.00	0.00	16.00		
4	CLAY	20.00	20.00	0.00	16.00		
5	POZIDRAIN 2	20.00	20.00	0.00	16.00		
6	REGULATION LAYER	10.00	10.00	0.00	45.00		
7	WASTE	10.00	10.00	0.00	45.00	Piezometric surface 1	
8	ALLUVIUM	18.00	18.00	6.00	0.00	2.00	6.00
9	GRAVEL	20.00	20.00	0.00	30.00	Piezometric surface 4	

GROUND WATER CONDITIONS

Unit wt. of water = 9.81 KN/M3

Grid line	1	2	3	4	5	6	7	8
X-Coord	0.00	0.75	0.77	1.00	1.02	2.83	5.46	10.23
Ground water level	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00

Grid line	9	10	11	12	13	14	15	16
X-Coord	17.48	21.28	29.07	29.93	29.95	30.40	30.85	30.87
Ground water level	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00

Grid line	17	18	19	20	21	22	23	24
X-Coord	33.40	34.55	35.81	45.45	48.71	49.84	50.20	50.89
Ground water level	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00

Grid line	25
X-Coord	60.87
Ground water level	4.00

Piezometric surfaces associated with individual strata

Grid line	1	2	3	4	5	6	7	8
X-Coord	0.00	0.75	0.77	1.00	1.02	2.83	6.46	10.23
Surface	Piezometric elevation							
1	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Grid line	9	10	11	12	13	14	15	16
X-Coord	17.48	21.28	29.07	29.93	29.95	30.40	30.85	30.87
Surface	Piezometric elevation							
1	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Grid line	17	18	19	20	21	22	23	24
X-Coord	33.40	34.55	35.81	45.45	48.71	49.84	50.20	50.89
Surface	Piezometric elevation							
1	6.01	6.00	6.00	6.00	6.00	6.00	6.00	6.00
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Grid line	25
X-Coord	60.87
Surface	Piezometric elevation
1	6.00
4	0.00

CIRCULAR SLIP SURFACE DATA

Grid of centres:	X	Y
Corner of grid	25.00	15.00
Grid increment	2.00	2.00
No. of grid lines	5	5

The grid of centres will be extended automatically
until a minimum factor of safety has been found.

Common point(s):	X	Y
Coordinates of (first) point	35.81	6.22
Increment between points	5.00	0.00

Number of points = 5

ANALYSIS OPTIONS

Method of analysis: BISHOP - Simplified : Horizontal interslice forces
Factors of safety calculated on Soil Strength
Partial factor of safety on tan(phi) = 1.000
Partial factor of safety on drained cohesion = 1.000
Partial factor of safety on undrained cohesion = 1.000
Partial factor of safety on soil weight = 1.000
Partial factor of safety on surcharge loads = 1.000
Minimum number of slices = 10

APPENDIX 2 SEPARATION LAYER - ANALYSIS FOR NON CIRCULAR FAILURE

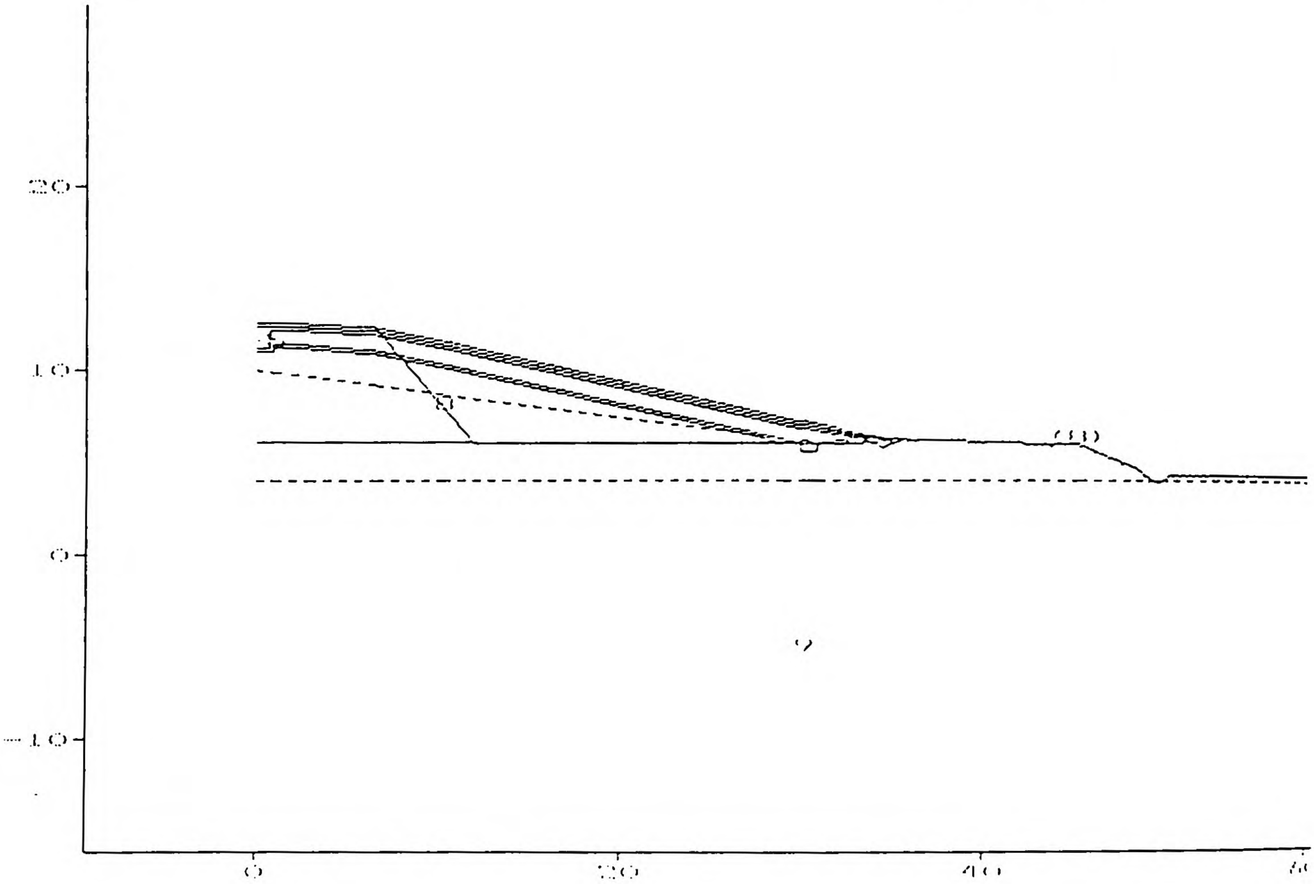
KENNEDY AND DONKIN LTD

Program: SLOPE Version 9R.01 Revision A01.B01.R19
Licensed from GEOSOLVE

[redacted] Eastern Extension
Section E separation upper range leachate draining

| Sheet No.
| Run No. ENC1A
|
| Job No. 026
| Made by : DJG
| Date: 4-03-1999
| Checked :

Units: KN,M



Scale = 1 : 412

Factor of safety = 1.750

KENNEDY AND DONKIN LTD | Sheet No.
| Run No. ENC1A

Program: SLOPE Version 9R.01 Revision A01.B01.R19
Licensed from GEOSOLVE

| Job No. 026
| Made by : DJG
| Date: 4-03-1999
| Checked :

[redacted] Eastern Extension
Section E separation upper range leachate draining

Units: KN,M

INPUT DATA

PROFILE DATA

Grid line	1	2	3	4	5	6	7	8
X-Coord	0.00	0.75	0.77	1.00	1.02	2.33	6.46	6.48
Stratum	**Y-Coordinates**							
1(GL)	12.58	12.58	12.58	12.58	12.58	12.58	12.31	12.31
2	12.38	12.38	12.38	12.38	12.38	12.38	12.10	12.10
3	12.37	12.37	12.37	12.37	12.37	12.37	12.09	12.09
4	11.22	11.22	12.17	12.17	12.17	12.17	11.89	11.89
5	11.22	11.22	12.17	12.17	12.17	12.17	11.89	11.89
6	10.97	10.97	10.97	10.97	11.42	11.42	11.13	11.13
7	10.96	10.96	10.96	10.96	11.42	11.41	11.12	11.12
8	10.96	10.96	10.96	10.96	11.22	11.21	10.92	10.92
9	6.03	6.03	6.03	6.03	6.03	6.03	6.03	6.03

Grid line	9	10	11	12	13	14	15	16
X-Coord	10.23	29.07	29.93	29.95	30.40	30.35	30.87	33.40
Stratum	**Y-Coordinates**							
1(GL)	11.58	7.41	7.26	7.25	7.17	7.09	7.08	6.63
2	11.38	7.21	7.05	7.05	6.96	6.88	6.88	6.43
3	11.37	7.20	7.04	7.03	6.95	6.87	6.87	6.42
4	11.17	7.00	6.84	6.84	6.75	6.67	6.67	6.22
5	11.16	7.00	6.84	6.84	6.75	6.67	6.67	6.22
6	10.39	6.24	6.08	6.07	6.19	6.00	6.00	6.22
7	10.39	6.23	6.07	5.49	5.49	5.49	6.00	6.22
8	10.18	6.03	6.07	5.49	5.49	5.49	6.00	6.22
9	6.03	6.03	6.07	5.49	5.49	5.49	6.00	6.22

Grid line	17	18	19	20	21	22	23	24
X-Coord	34.55	35.81	45.45	48.71	49.84	50.20	50.89	60.87
Stratum	**Y-Coordinates**							
1(GL)	6.42	6.22	5.97	4.69	3.82	3.84	4.41	4.26
2	6.22	6.22	5.97	4.69	3.82	3.84	4.41	4.26
3	6.22	6.22	5.97	4.69	3.82	3.84	4.41	4.26
4	5.72	6.22	5.97	4.69	3.82	3.84	4.41	4.26
5	5.72	6.22	5.97	4.69	3.82	3.84	4.41	4.26
6	5.72	6.22	5.97	4.69	3.82	3.84	4.41	4.26
7	5.72	6.22	5.97	4.69	3.82	3.84	4.41	4.26
8	5.72	6.22	5.97	4.69	3.82	3.84	4.41	4.26
9	5.72	6.22	5.97	4.69	3.82	3.84	4.41	4.26

SOIL PROPERTIES

--- Stratum --- No.	Description	Bulk unit wt. below GWL KN/M3	Bulk unit wt. above GWL KN/M3	Strength parameters C KN/M2	Phi (deg)	dC/dY KN/M2/M	Datum for C
1	DRAINAGE STONE	20.00	20.00	0.00	33.00		
2	POZIDRAIN 1	10.00	10.00	0.00	10.00		
3	COVER	18.00	18.00	25.00	0.00		
4	HDPE	10.00	10.00	0.00	8.00		
5	CLAY	20.00	20.00	30.00	0.00		
6	POZIDRAIN 2	10.00	10.00	0.00	10.00		
7	REGULATION LAYER	20.00	18.00	30.00	0.00		
8	WASTE	11.00	11.00	0.00	27.00	Piezometric surface 1	
9	ALLUVIUM	18.00	16.00	6.00	0.00	13.00	6.00

GROUND WATER CONDITIONS

Unit wt. of water = 9.81 KN/M3

Grid line	1	2	3	4	5	6	7	8
X-Coord	0.00	0.75	0.77	1.00	1.02	2.83	6.46	6.48
Ground water level	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00

Grid line	9	10	11	12	13	14	15	16
X-Coord	10.23	29.07	29.93	29.95	30.40	30.85	30.87	33.40
Ground water level	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00

Grid line	17	18	19	20	21	22	23	24
X-Coord	34.55	35.81	45.45	48.71	49.84	50.20	50.89	60.87
Ground water level	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00

Piezometric surfaces associated with individual strata

Grid line	1	2	3	4	5	6	7	8
X-Coord	0.00	0.75	0.77	1.00	1.02	2.83	6.46	6.48
Surface / Piezometric elevation								
1	10.00	9.90	9.90	9.87	9.87	9.63	9.16	9.15

Grid line	9	10	11	12	13	14	15	16
X-Coord	10.23	29.07	29.93	29.95	30.40	30.85	30.87	33.40
Surface / Piezometric elevation								
1	8.68	6.24	6.12	6.12	6.06	6.01	6.00	6.01

Grid line	17	18	19	20	21	22	23	24
X-Coord	34.55	35.81	45.45	48.71	49.84	50.20	50.89	60.87
Surface / Piezometric elevation								
1	6.01	6.02	5.75	4.43	3.61	3.64	4.14	4.06

NON-CIRCULAR SLIP SURFACE DATA

Point no.	X Coord	Y Coord
1	6.46	12.31
2	12.00	6.00
3	33.40	6.00
4	35.81	6.22

```
ANALYSIS OPTIONS
 Method of analysis: JANBU  - Horizontal interslice forces
  Factors of safety calculated on Soil Strength
  Partial factor of safety on tan(phi)           = 1.000
  Partial factor of safety on drained cohesion   = 1.000
  Partial factor of safety on undrained cohesion = 1.000
  Partial factor of safety on soil weight        = 1.000
  Partial factor of safety on surcharge loads    = 1.000
  Minimum number of slices = 10
```

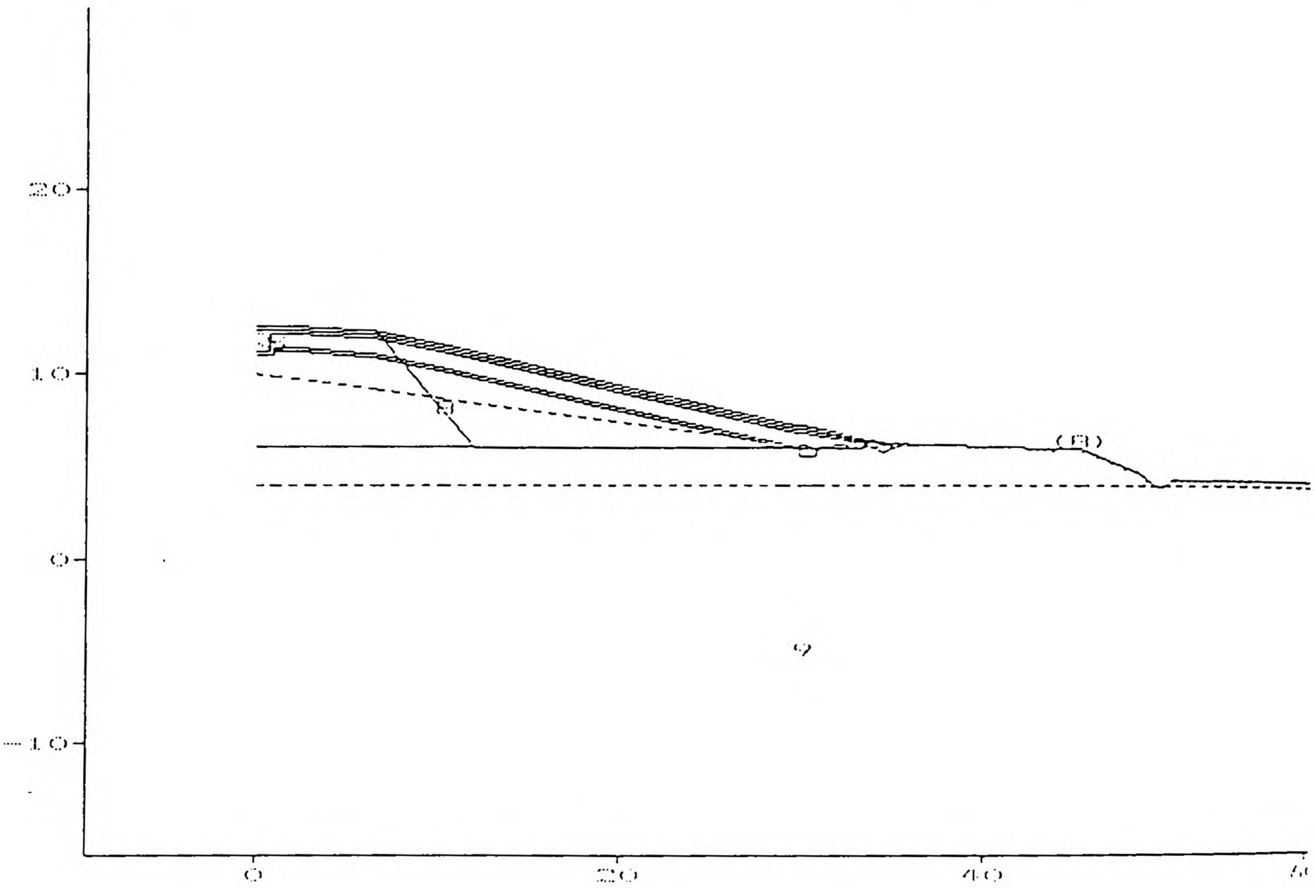
KENNEDY AND DONKIN LTD

Program: SLOPE Version 9R.01 Revision A01.B01.R19
Licensed from GEOSOLVE

[redacted] Eastern Extension
Section E separation lower range leachate draining

| Sheet No.
| Run No. ENC1ALB
|
| Job No. 026
| Made by : DJG
| Date: 4-03-1999
| Checked :

Units: KN,M



Scale = 1 : 412

Factor of safety = 1.193

KENNEDY AND DONKIN LTD | Sheet No.
| Run No. ENC1ALB
Program: SLOPE Version 9R.01 Revision A01.B01.R19 |
Licensed from GEOSOLVE | Job No. 026
| Made by : DJG
[redacted] Eastern Extension | Date: 4-03-1999
Section E separation lower range leachate draining | Checked :

Units: KN,M

INPUT DATA

PROFILE DATA

Grid line	1	2	3	4	5	6	7	8
X-Coord	0.00	0.75	0.77	1.00	1.02	2.83	6.46	6.48
Stratum	Y-Coordinates							
1(GL)	12.58	12.58	12.58	12.58	12.58	12.58	12.31	12.31
2	12.38	12.38	12.38	12.38	12.38	12.38	12.10	12.10
3	12.37	12.37	12.37	12.37	12.37	12.37	12.09	12.09
4	11.22	11.22	12.17	12.17	12.17	12.17	11.89	11.89
5	11.22	11.22	12.17	12.17	12.17	12.17	11.89	11.89
6	10.97	10.97	10.97	10.97	11.42	11.42	11.13	11.13
7	10.96	10.96	10.96	10.96	11.42	11.41	11.12	11.12
8	10.96	10.96	10.96	10.96	11.22	11.21	10.92	10.92
9	6.03	6.03	6.03	6.03	6.03	6.03	6.03	6.03

Grid line	9	10	11	12	13	14	15	16
X-Coord	10.23	29.07	29.93	29.95	30.40	30.85	30.87	33.40
Stratum	Y-Coordinates							
1(GL)	11.58	7.41	7.26	7.25	7.17	7.09	7.08	6.63
2	11.38	7.21	7.05	7.05	6.96	6.88	6.88	6.43
3	11.37	7.20	7.04	7.03	6.95	6.87	6.87	6.42
4	11.17	7.00	6.84	6.84	6.75	6.67	6.67	6.22
5	11.16	7.00	6.84	6.84	6.75	6.67	6.67	6.22
6	10.39	6.24	6.08	6.07	6.19	6.00	6.00	6.22
7	10.39	6.23	6.07	5.49	5.49	5.49	6.00	6.22
8	10.18	6.03	6.07	5.49	5.49	5.49	6.00	6.22
9	6.03	6.03	6.07	5.49	5.49	5.49	6.00	6.22

Grid line	17	18	19	20	21	22	23	24
X-Coord	34.55	35.81	45.45	48.71	49.84	50.20	50.89	60.87
Stratum	Y-Coordinates							
1(GL)	6.42	6.22	5.97	4.69	3.82	3.84	4.41	4.26
2	6.22	6.22	5.97	4.69	3.82	3.84	4.41	4.26
3	6.22	6.22	5.97	4.69	3.82	3.84	4.41	4.26
4	5.72	6.22	5.97	4.69	3.82	3.84	4.41	4.26
5	5.72	6.22	5.97	4.69	3.82	3.84	4.41	4.26
6	5.72	6.22	5.97	4.69	3.82	3.84	4.41	4.26
7	5.72	6.22	5.97	4.69	3.82	3.84	4.41	4.26
8	5.72	6.22	5.97	4.69	3.82	3.84	4.41	4.26
9	5.72	6.22	5.97	4.69	3.82	3.84	4.41	4.26

SOIL PROPERTIES

--- Stratum --- No.	Description	Bulk unit wt. below GWL KN/M3	above GWL KN/M3	-------Strength parameters------- C KN/M2	Phi (deg)	dC/dY KN/M2/M	Datum for C
1	DRAINAGE STONE	20.00	20.00	0.00	33.00		
2	POZIDRAIN 1	10.00	10.00	0.00	10.00		
3	COVER	18.00	18.00	15.00	0.00		
4	HDPE	10.00	10.00	0.00	6.00		
5	CLAY	20.00	20.00	15.00	0.00		
6	POZIDRAIN 2	10.00	10.00	0.00	6.00		
7	REGULATION LAYER	15.00	15.00	0.00	20.00		
8	WASTE	15.00	15.00	0.00	20.00	Piezometric surface 1	
9	ALLUVIUM	18.00	16.00	6.00	0.00	13.00	6.00

GROUND WATER CONDITIONS

Unit wt. of water = 9.81 KN/M3

Grid line	1	2	3	4	5	6	7	8
X-Coord	0.00	0.75	0.77	1.00	1.02	2.83	6.46	6.48
Ground water level	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00

Grid line	9	10	11	12	13	14	15	16
X-Coord	10.23	29.07	29.93	29.95	30.40	30.85	30.87	33.40
Ground water level	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00

Grid line	17	18	19	20	21	22	23	24
X-Coord	34.55	35.81	45.45	48.71	49.84	50.20	50.89	60.87
Ground water level	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00

Piezometric surfaces associated with individual strata

Grid line	1	2	3	4	5	6	7	8
X-Coord	0.00	0.75	0.77	1.00	1.02	2.83	6.46	6.48
Surface / Piezometric elevation								
1	10.00	9.90	9.90	9.87	9.87	9.63	9.16	9.16

Grid line	9	10	11	12	13	14	15	16
X-Coord	10.23	29.07	29.93	29.95	30.40	30.85	30.87	33.40
Surface / Piezometric elevation								
1	8.68	6.24	6.12	6.12	6.06	6.01	6.00	6.01

Grid line	17	18	19	20	21	22	23	24
X-Coord	34.55	35.81	45.45	48.71	49.84	50.20	50.89	60.87
Surface / Piezometric elevation								
1	6.01	6.02	5.75	4.43	3.61	3.64	4.14	4.06

NON-CIRCULAR SLIP SURFACE DATA

Point no.	X Coord	Y Coord
1	6.46	12.31
2	12.00	6.00
3	33.40	6.00
4	35.81	6.22

ANALYSIS OPTIONS

```
Method of analysis: JANBU  - Horizontal interslice forces
 Factors of safety calculated on Soil Strength
 Partial factor of safety on tan(phi)             = 1.000
 Partial factor of safety on drained cohesion     = 1.000
 Partial factor of safety on undrained cohesion = 1.000
 Partial factor of safety on soil weight          = 1.000
 Partial factor of safety on surcharge loads      = 1.000
 Minimum number of slices = 10
```

APPENDIX 3 SEPARATION LAYER - FAILURE ALONG HDPE / ABTEX INTERFACE

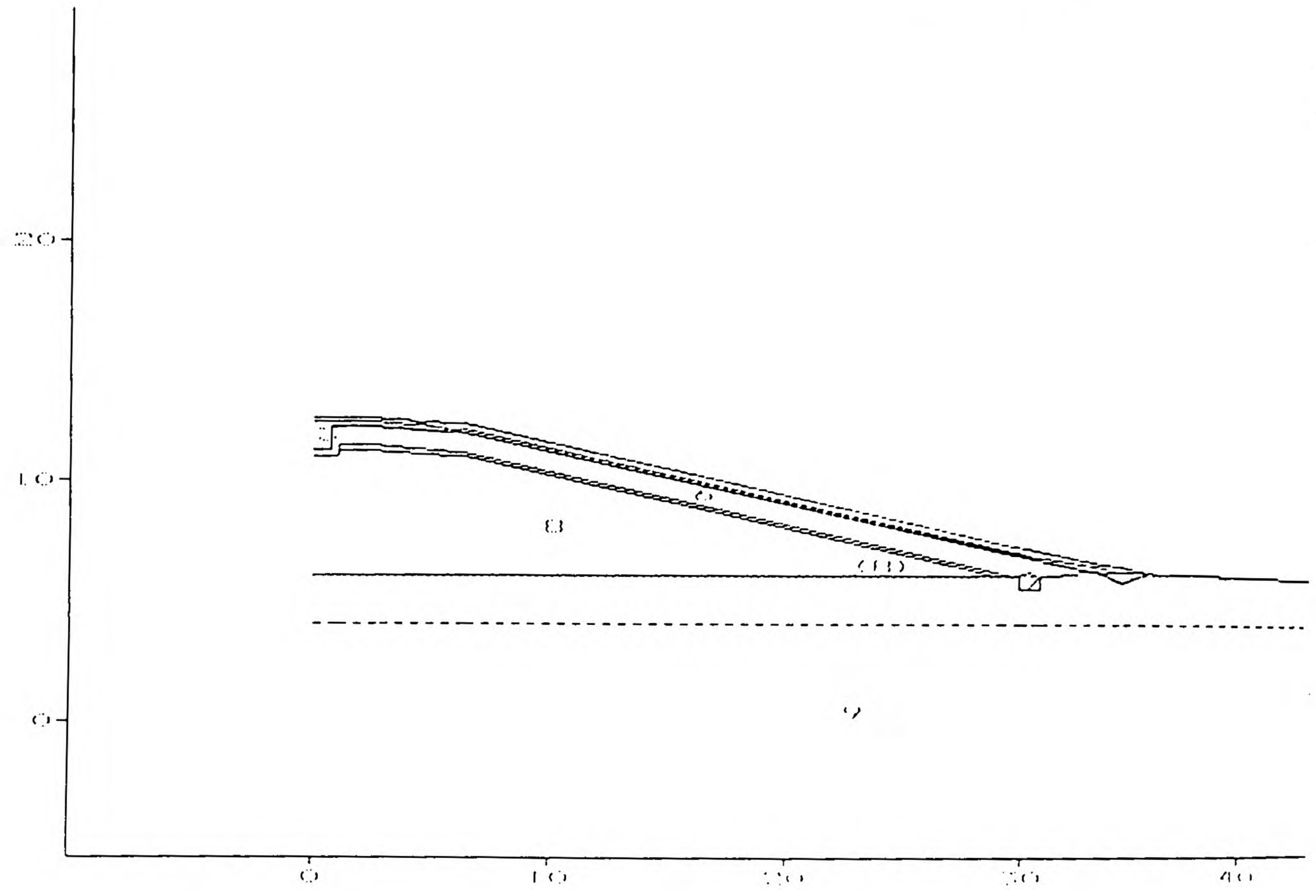
KENNEDY AND DONKIN LTD

Program: SLOPE Version 9R.01 Revision A01.B01.R19
Licensed from GEOSOLVE

[redacted] Eastern Extension
Section E separation layer interface shear

Sheet No.	
Run No.	ENC1
Job No.	026
Made by :	DJG
Date:	4-03-1999
Checked :	

Units: KN,M



Scale = 1 : 317

Factor of safety = 1.563

KENNEDY AND DONKIN LTD | Sheet No.
| Run No. ENC1
Program: SLOPE Version 9R.01 Revision A01.B01.R19
Licensed from GEOSOLVE | Job No. 026
| Made by : DJG
[redacted] Eastern Extension | Date: 4-03-1999
Section E separation layer interface shear | Checked :

Units: KN,M

INPUT DATA

PROFILE DATA

Grid line	1	2	3	4	5	6	7	8
X-Coord	0.00	0.75	0.77	1.00	1.02	2.83	6.46	6.48
Stratum	Y-Coordinates							
1(GL)	12.58	12.58	12.58	12.58	12.58	12.58	12.31	12.30
2	12.38	12.38	12.38	12.38	12.38	12.38	12.10	12.10
3	12.37	12.37	12.37	12.37	12.37	12.37	12.09	12.09
4	11.27	11.27	12.22	12.22	12.22	12.22	11.94	11.94
5	11.22	11.22	12.17	12.17	12.17	12.17	11.89	11.89
6	11.22	11.22	12.17	12.17	12.17	12.17	11.89	11.89
7	10.97	10.97	10.97	10.97	11.42	11.42	11.13	11.13
8	10.96	10.96	10.96	10.96	11.22	11.21	10.92	10.92
9	6.03	6.03	6.03	6.03	6.03	6.03	6.03	6.03

Grid line	9	10	11	12	13	14	15	16
X-Coord	29.07	29.93	29.95	30.40	30.85	30.87	33.40	34.55
Stratum	Y-Coordinates							
1(GL)	7.41	7.26	7.25	7.17	7.09	7.08	6.63	6.42
2	7.21	7.05	7.05	6.96	6.88	6.88	6.43	6.22
3	7.20	7.04	7.03	6.95	6.87	6.87	6.42	6.22
4	7.05	6.89	6.89	6.81	6.73	6.72	6.27	5.77
5	7.00	6.84	6.84	6.75	6.67	6.67	6.22	5.72
6	7.00	6.84	6.84	6.75	6.67	6.67	6.22	5.72
7	6.24	6.08	6.07	6.19	6.00	6.00	6.22	5.72
8	6.03	6.07	5.49	5.49	5.49	6.00	6.22	5.72
9	6.03	6.07	5.49	5.49	5.49	6.00	6.22	5.72

Grid line	17	18	19	20	21	22	23
X-Coord	35.81	45.45	48.71	49.84	50.20	50.89	60.87
Stratum	Y-Coordinates						
1(GL)	6.22	5.97	4.69	3.82	3.84	4.41	4.26
2	6.22	5.97	4.69	3.82	3.84	4.41	4.26
3	6.22	5.97	4.69	3.82	3.84	4.41	4.26
4	6.22	5.97	4.69	3.82	3.84	4.41	4.26
5	6.22	5.97	4.69	3.82	3.84	4.41	4.26
6	6.22	5.97	4.69	3.82	3.84	4.41	4.26
7	6.22	5.97	4.69	3.82	3.84	4.41	4.26
8	6.22	5.97	4.69	3.82	3.84	4.41	4.26
9	6.22	5.97	4.69	3.82	3.84	4.41	4.26

SOIL PROPERTIES

--- Stratum --- No.	Description	Bulk unit wt. below GWL KN/M3	above GWL KN/M3	-------Strength parameters------- C KN/M2	Phi (deg)	dC/dY KN/M2/M	Datum for C
1	DRAINAGE STONE	20.00	20.00	0.00	33.00		
2	POZIDRAIN 1	10.00	10.00	0.00	10.00		
3	COVER	18.00	18.00	20.00	0.00		
4	ABTEX	10.00	10.00	0.00	6.00		
5	HDPE	10.00	10.00	0.00	6.00		
6	CLAY	18.00	18.00	30.00	0.00		
7	POZIDRAIN 2	10.00	10.00	0.00	10.00		
8	WASTE	12.00	12.00	0.00	20.00	Piezometric surface 1	
9	ALLUVIUM	18.00	16.00	10.00	0.00	13.00	6.00

GROUND WATER CONDITIONS

Unit wt. of water = 9.81 KN/M3

Grid line	1	2	3	4	5	6	7	8
X-Coord	0.00	0.75	0.77	1.00	1.02	2.33	6.46	6.48
Ground water level	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00

Grid line	9	10	11	12	13	14	15	16
X-Coord	29.07	29.93	29.95	30.40	30.85	30.87	33.40	34.55
Ground water level	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00

Grid line	17	18	19	20	21	22	23
X-Coord	35.81	45.45	48.71	49.84	50.20	50.39	60.87
Ground water level	4.00	4.00	4.00	4.00	4.00	4.00	4.00

Piezometric surfaces associated with individual strata

Grid line	1	2	3	4	5	6	7	8
X-Coord	0.00	0.75	0.77	1.00	1.02	2.33	6.46	6.48
Surface / Piezometric elevation								
1	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00

Grid line	9	10	11	12	13	14	15	16
X-Coord	29.07	29.93	29.95	30.40	30.85	30.87	33.40	34.55
Surface / Piezometric elevation								
1	6.00	6.00	6.00	6.00	6.00	6.00	6.01	6.01

Grid line	17	18	19	20	21	22	23
X-Coord	35.81	45.45	48.71	49.84	50.20	50.39	60.87
Surface / Piezometric elevation							
1	6.02	5.75	4.43	3.61	3.64	4.14	4.06

NON-CIRCULAR SLIP SURFACE DATA

Point no.	X Coord	Y Coord
1	3.55	12.53
2	6.48	11.89
3	29.07	7.00
4	33.40	6.22
5	35.81	6.22

ANALYSIS OPTIONS

Method of analysis: JANBU - Horizontal interslice forces

Factors of safety calculated on Soil Strength

Partial factor of safety on tan(phi) = 1.000

Partial factor of safety on drained cohesion = 1.000

Partial factor of safety on undrained cohesion = 1.000

Partial factor of safety on soil weight = 1.000

Partial factor of safety on surcharge loads = 1.000

Minimum number of slices = 10

APPENDIX 4 EASTERN BUND - ANALYSIS FOR CIRCULAR FAILURE

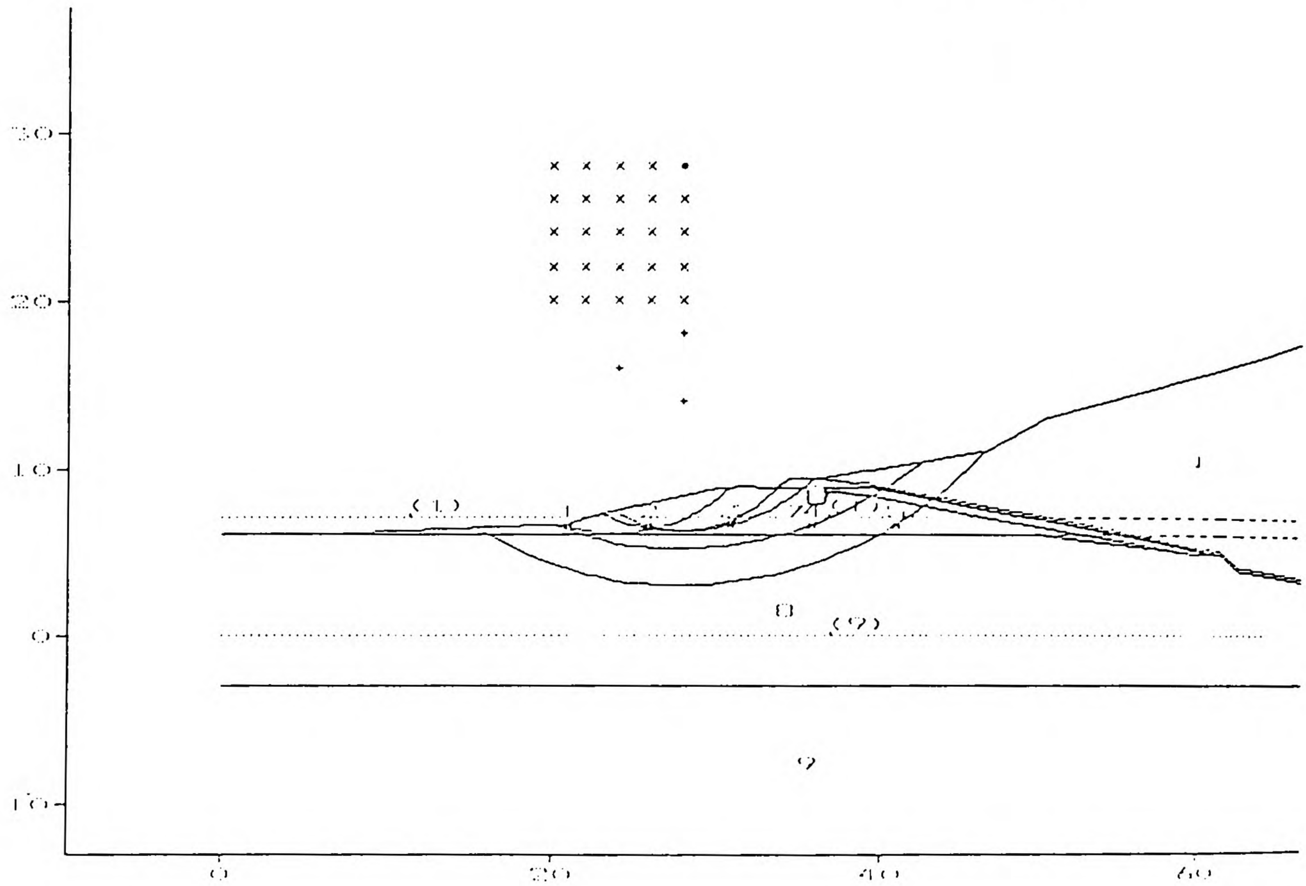
KENNEDY AND DONKIN LTD

Program: SLOPE Version 9R.01 Revision A01.B01.R19
Licensed from GEOSOLVE

[redacted] Eastern Extension
Section F Eastern Bund failure parameters

| Sheet No.
| Run No. FCBVLB
|
| Job No. 026
| Made by : CJG
| Date: 4-03-1999
| Checked :

Units: KN,M



Scale = 1 : 455

---- Common point -----			----------- Critical circle ---------			
Point no.	X coord	Y coord	---- Centre ---- X	Y	Radius	Factor of safety
1	20.88	6.58	24.00	16.00	9.92	0.869
2	25.88	6.58	28.00	14.00	7.72	1.041
3	30.88	6.58	28.00	18.00	11.78	1.054
4	35.88	6.58	28.00	28.00	22.82	1.790
5	40.88	6.58	28.00	28.00	24.99	3.528

KENNEDY AND DONKIN LTD

Program: SLOPE Version 9R.01 Revision A01.B01.R19	Sheet No.
Licensed from GEOSOLVE	Run No. FCBVLB
	Job No. 026
	Made by : DJG
[redacted] Eastern Extension	Date: 4-03-1999
Section F Eastern Bund failure parameters	Checked :

Units: KN,M

INPUT DATA

PROFILE DATA

Grid line	1	2	3	4	5	6	7	8
X-Coord	0.00	9.14	20.88	23.19	29.82	32.41	33.64	34.53
Stratum	Y-Coordinates							
1(GL)	6.02	6.10	6.58	7.28	8.63	8.89	8.84	9.38
2	6.02	6.10	6.58	7.28	8.63	8.89	8.84	9.38
3	6.02	6.10	6.58	7.28	8.63	8.89	8.84	9.38
4	6.02	6.10	6.58	7.28	8.63	8.89	8.84	8.84
5	6.02	6.10	6.58	7.28	8.63	8.89	8.84	8.84
6	6.02	6.10	6.58	7.28	8.63	8.89	8.84	8.84
7	6.02	6.10	6.58	7.28	8.63	8.89	8.84	8.84
8	6.02	6.02	6.02	6.02	6.02	6.02	6.02	6.02
9	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00

Grid line	9	10	11	12	13	14	15	16
X-Coord	35.44	35.54	36.54	36.64	39.31	39.63	46.44	50.00
Stratum	Y-Coordinates							
1(GL)	9.36	9.36	9.35	9.35	9.80	9.85	11.00	13.00
2	9.36	9.36	9.35	9.35	9.09	9.06	7.76	7.13
3	9.36	9.36	9.35	9.35	8.86	8.86	7.56	6.93
4	8.84	7.83	7.83	8.78	8.85	8.85	7.55	6.92
5	8.84	7.82	7.82	8.73	8.84	8.84	7.54	6.91
6	8.84	7.82	7.82	8.68	8.39	8.33	7.03	6.48
7	8.84	7.81	7.81	8.62	8.38	8.33	7.03	6.47
8	6.02	6.02	6.02	6.02	6.02	6.02	6.02	6.02
9	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00

Grid line	17	18	19	20	21	22	23	24
X-Coord	59.46	61.83	63.06	63.08	69.03	73.57	75.33	82.47
Stratum	Y-Coordinates							
1(GL)	15.41	16.01	16.32	16.33	17.84	19.00	19.34	20.74
2	5.47	5.14	4.17	4.17	3.48	3.64	4.00	4.00
3	5.27	4.88	3.97	3.97	3.28	3.44	3.80	3.80
4	5.26	4.87	3.96	3.96	3.28	3.44	3.79	3.79
5	5.25	4.87	3.96	3.96	3.28	3.44	3.79	3.79
6	5.00	4.87	3.96	3.96	3.28	3.44	3.79	3.79
7	4.99	4.86	3.95	3.96	3.28	3.44	3.79	3.79
8	4.99	4.86	3.95	3.96	3.28	3.44	3.79	3.79
9	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00

PROFILE DATA (continued)

Grid line 25
X-Coord 135.00

Stratum	Y-Coordinates
1(GL)	31.00
2	3.98
3	3.78
4	3.77
5	3.77
6	3.77
7	3.77
8	3.77
9	-3.00

SOIL PROPERTIES

--- Stratum --- No.	Description	Bulk unit wt. below GWL KN/M3	above GWL KN/M3	-------Strength parameters------- C KN/M2	Phi (deg)	dC/dY KN/M2/M	Datum for C
1	WASTE	11.00	11.00	0.00	27.00	Piezometric surface 3	
2	DRAINAGE STONE	20.00	20.00	0.00	33.00		
3	CLAY COVER	17.00	17.00	15.00	0.00		
4	HDPE/ABTEX	10.00	10.00	0.00	8.00		
5	COMPACTED CLAY	18.00	18.00	25.00	0.00		
6	GEOGRID	10.00	10.00	0.00	30.00		
7	CLAY BUND	18.00	18.00	3.00	0.00		
8	ALLUVIUM	18.00	18.00	6.00	0.00	13.00	6.02
9	GRAVEL	20.00	20.00	0.00	35.00	Piezometric surface 2	

GROUND WATER CONDITIONS
Unit wt. of water = 9.81 KN/M3

Grid line	1	2	3	4	5	6	7	8
X-Coord	0.00	9.14	20.88	23.19	29.82	32.41	33.64	34.53
Ground water level	6.02	6.02	6.02	6.02	6.02	6.02	6.02	6.02

Grid line	9	10	11	12	13	14	15	16
X-Coord	35.44	35.54	36.54	36.64	39.31	39.63	46.44	50.00
Ground water level	6.02	6.02	6.02	6.02	6.02	6.02	6.02	6.02

Grid line	17	18	19	20	21	22	23	24
X-Coord	59.46	61.83	63.06	63.08	69.03	73.57	75.33	82.47
Ground water level	6.02	6.02	6.02	6.02	6.02	6.02	6.02	6.02

Grid line	25
X-Coord	135.00
Ground water level	6.02

Piezometric surfaces associated with individual strata

Grid line	1	2	3	4	5	6	7	8
X-Coord	0.00	9.14	20.88	23.19	29.82	32.41	33.64	34.53
Surface	Piezometric elevation							
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00

Grid line	9	10	11	12	13	14	15	16
X-Coord	35.44	35.54	36.54	36.64	39.31	39.63	46.44	50.00
Surface	Piezometric elevation							
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00

Grid line	17	18	19	20	21	22	23	24
X-Coord	59.46	61.83	63.06	63.08	69.03	73.57	75.33	82.47
Surface	Piezometric elevation							
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00

Grid line	25
X-Coord	135.00
Surface	Piezometric elevation
2	0.00
3	7.00

CIRCULAR SLIP SURFACE DATA

Grid of centres:	X	Y
Corner of grid	20.00	20.00
Grid increment	2.00	2.00
No. of grid lines	5	5

The grid of centres will be extended automatically
until a minimum factor of safety has been found.

Common point(s):	X	Y
Coordinates of (first) point	20.88	6.58
Increment between points	5.00	0.00

Number of points = 5

ANALYSIS OPTIONS

Method of analysis: BISHOP - Simplified : Horizontal interslice forces
Factors of safety calculated on Soil Strength
Partial factor of safety on tan(phi) = 1.000
Partial factor of safety on drained cohesion = 1.000
Partial factor of safety on undrained cohesion = 1.000
Partial factor of safety on soil weight = 1.000
Partial factor of safety on surcharge loads = 1.000
Minimum number of slices = 10

APPENDIX 5 EASTERN BUND - ANALYSIS FOR CIRCULAR FAILURE POST RESTORATION

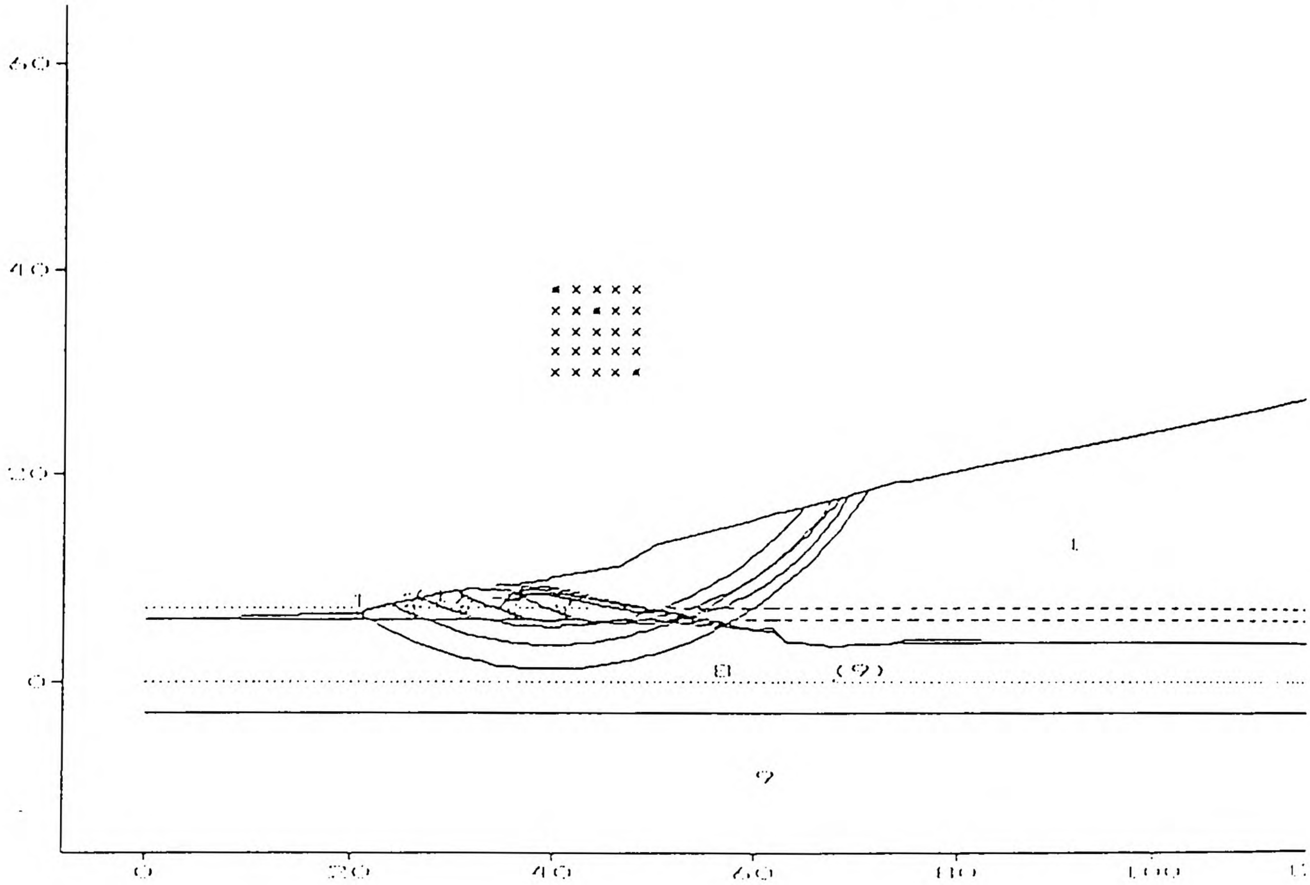
KENNEDY AND DONKIN LTD

Program: SLOPE Version 9R.01 Revision A01.B01.R19
Licensed from GEOSOLVE

[redacted] Eastern Extension
Section F Eastern Bund lower range parameters

| Sheet No. |
| Run No. FCBLB |
| Job No. 026 |
| Made by : DJG |
| Date: 4-03-1999 |
| Checked : |

Units: KN,M



Scale = 1 : 738

---- Common point -----			----------- Critical circle ---------			
Point	X	Y	---- Centre ----		Radius	Factor of
no.	coord	coord	X	Y		safety
1	20.88	6.58	40.00	38.00	36.78	2.319
2	25.88	6.58	40.00	38.00	34.45	1.741
3	30.88	6.58	40.00	38.00	32.72	1.397
4	35.88	6.58	44.00	36.00	30.52	1.328
5	40.88	6.58	48.00	30.00	24.48	1.282

KENNEDY AND DONKIN LTD

Program: SLOPE Version 9R.01 Revision A01.B01.R19
Licensed from GEOSOLVE

[redacted] Eastern Extension
Section F Eastern Bund

Sheet No.	
Run No.	FCBLB
Job No.	026
Made by :	DJG
Date:	4-03-1999
Checked :	

Units: KN,M

INPUT DATA

PROFILE DATA

Grid line	1	2	3	4	5	6	7	8
X-Coord	0.00	9.14	20.88	23.19	29.82	32.41	33.64	34.53
Stratum	Y-Coordinates							
1(GL)	6.02	6.10	6.58	7.28	8.63	8.89	8.84	9.38
2	6.02	6.10	6.58	7.28	8.63	8.89	8.84	9.38
3	6.02	6.10	6.58	7.28	8.63	8.89	8.84	9.38
4	6.02	6.10	6.58	7.28	8.63	8.89	8.84	8.84
5	6.02	6.10	6.58	7.28	8.63	8.89	8.84	8.84
6	6.02	6.10	6.58	7.28	8.63	8.89	8.84	8.84
7	6.02	6.10	6.58	7.28	8.63	8.89	8.84	8.84
8	6.02	6.02	6.02	6.02	6.02	6.02	6.02	6.02
9	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00

Grid line	9	10	11	12	13	14	15	16
X-Coord	35.44	35.54	36.54	36.64	39.31	39.63	46.44	50.00
Stratum	Y-Coordinates							
1(GL)	9.36	9.36	9.35	9.35	9.80	9.85	11.00	13.00
2	9.36	9.36	9.35	9.35	9.09	9.06	7.76	7.13
3	9.36	9.36	9.35	9.35	8.86	8.86	7.56	6.93
4	8.84	7.83	7.83	8.78	8.85	8.85	7.55	6.92
5	8.84	7.82	7.82	8.73	8.84	8.84	7.54	6.91
6	8.84	7.82	7.82	8.68	8.39	8.33	7.03	6.48
7	8.84	7.81	7.81	8.62	8.38	8.33	7.03	6.47
8	6.02	6.02	6.02	6.02	6.02	6.02	6.02	6.02
9	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00

Grid line	17	18	19	20	21	22	23	24
X-Coord	59.46	61.83	63.06	63.08	69.03	73.57	75.33	82.47
Stratum	Y-Coordinates							
1(GL)	15.41	16.01	16.32	16.33	17.84	19.00	19.34	20.74
2	5.47	5.14	4.17	4.17	3.48	3.64	4.00	4.00
3	5.27	4.88	3.97	3.97	3.28	3.44	3.80	3.80
4	5.26	4.87	3.96	3.96	3.28	3.44	3.79	3.79
5	5.25	4.87	3.96	3.96	3.28	3.44	3.79	3.79
6	5.00	4.87	3.96	3.96	3.28	3.44	3.79	3.79
7	4.99	4.86	3.95	3.96	3.28	3.44	3.79	3.79
8	4.99	4.86	3.95	3.96	3.28	3.44	3.79	3.79
9	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00

PROFILE DATA (continued)

Grid line 25
X-Coord 135.00

Stratum	Y-Coordinates
1(GL)	31.00
2	3.98
3	3.78
4	3.77
5	3.77
6	3.77
7	3.77
8	3.77
9	-3.00

SOIL PROPERTIES

--- Stratum --- No.	Description	Bulk unit wt. below GWL KN/M3	Bulk unit wt. above GWL KN/M3	Strength parameters C KN/M2	Phi (deg)	dC/dY KN/M2/M	Datum for C
1	WASTE	15.00	15.00	0.00	20.00	Piezometric surface 3	
2	DRAINAGE STONE	20.00	20.00	0.00	16.00		
3	CLAY COVER	20.00	20.00	8.00	0.00		
4	HDPE/ABTEX	10.00	10.00	0.00	6.00		
5	COMPACTED CLAY	20.00	20.00	15.00	0.00		
6	GEOGRID	10.00	10.00	0.00	6.00		
7	CLAY BUND	20.00	20.00	15.00	0.00		
8	ALLUVIUM	18.00	18.00	6.00	0.00	13.00	6.02
9	GRAVEL	20.00	20.00	0.00	30.00	Piezometric surface 2	

GROUND WATER CONDITIONS
Unit wt. of water = 9.81 KN/M3

Grid line	1	2	3	4	5	6	7	8
X-Coord	0.00	9.14	20.88	23.19	29.82	32.41	33.64	34.53
Ground water level	6.02	6.02	6.02	6.02	6.02	6.02	6.02	6.02

Grid line	9	10	11	12	13	14	15	16
X-Coord	35.44	35.54	36.54	36.64	39.31	39.63	46.44	50.00
Ground water level	6.02	6.02	6.02	6.02	6.02	6.02	6.02	6.02

Grid line	17	18	19	20	21	22	23	24
X-Coord	59.46	61.83	63.06	63.08	69.03	73.57	75.33	82.47
Ground water level	6.02	6.02	6.02	6.02	6.02	6.02	6.02	6.02

Grid line	25
X-Coord	135.00
Ground water level	6.02

Piezometric surfaces associated with individual strata

Grid line	1	2	3	4	5	6	7	8
X-Coord	0.00	9.14	20.88	23.19	29.82	32.41	33.64	34.53
Surface	Piezometric elevation							
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00

Grid line	9	10	11	12	13	14	15	16
X-Coord	35.44	35.54	36.54	36.64	39.31	39.63	46.44	50.00
Surface	Piezometric elevation							
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00

Grid line	17	18	19	20	21	22	23	24
X-Coord	59.46	61.83	63.06	63.08	69.03	73.57	75.33	82.47
Surface	Piezometric elevation							
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00

Grid line	25
X-Coord	135.00
Surface	Piezometric elevation
2	0.00
3	7.00

CIRCULAR SLIP SURFACE DATA

Grid of centres:	X	Y
Corner of grid	40.00	30.00
Grid increment	2.00	2.00
No. of grid lines	5	5

The grid of centres will be extended automatically until a minimum factor of safety has been found.

Common point(s):	X	Y
Coordinates of (first) point	20.88	6.58
Increment between points	5.00	0.00

Number of points = 5

ANALYSIS OPTIONS

Method of analysis: BISHOP - Simplified : Horizontal interslice forces

Factors of safety calculated on Soil Strength

Partial factor of safety on tan(phi) = 1.000

Partial factor of safety on drained cohesion = 1.000

Partial factor of safety on undrained cohesion = 1.000

Partial factor of safety on soil weight = 1.000

Partial factor of safety on surcharge loads = 1.000

Minimum number of slices = 10

KENNEDY AND DONKIN LTD

Program: SLOPE Version 9R.01 Revision A01.B01.R19
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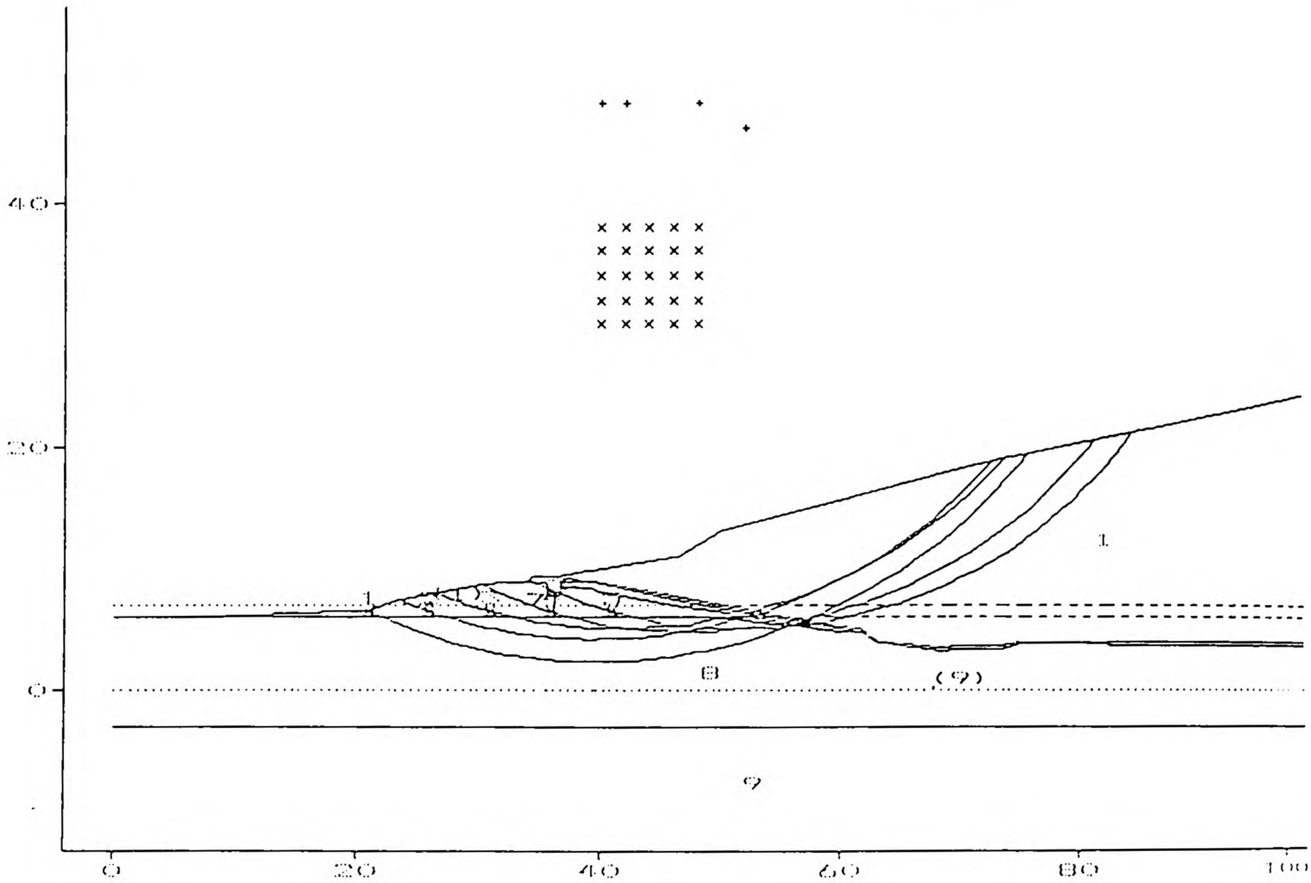
[redacted] Eastern Extension
Section F Eastern Bund upper range parameters

| Sheet No. |
| Run No. FCBUB |
| Job No. 026 |
| Made by : DJG |
| Date: 4-03-1999 |
| Checked : |

Units: KN,M



Scale = 1 : 621

---- Common point -----			---------- Critical circle ---------			
Point no.	X coord	Y coord	---- Centre ---- X	Y	Radius	Factor of safety
1	20.88	6.58	40.00	48.00	45.62	2.730
2	25.88	6.58	40.00	48.00	43.76	2.264
3	30.88	6.58	42.00	48.00	42.89	2.139
4	35.88	6.58	48.00	48.00	43.16	2.130
5	40.88	6.58	52.00	46.00	40.96	2.104

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Program: SLOPE Version 9R.01 Revision A01.B01.R19
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[redacted] Eastern Extension
Section F Eastern Bund upper range parameters

Sheet No.	
Run No.	FCBUB
Job No.	026
Made by :	DJG
Date:	4-03-1999
Checked :	

Units: KN,M

INPUT DATA

PROFILE DATA

Grid line	1	2	3	4	5	6	7	8
X-Coord	0.00	9.14	20.88	23.19	29.82	32.41	33.64	34.53
Stratum	Y-Coordinates							
1(GL)	6.02	6.10	6.58	7.28	8.63	8.89	8.84	9.38
2	6.02	6.10	6.58	7.28	8.63	8.89	8.84	9.38
3	6.02	6.10	6.58	7.28	8.63	8.89	8.84	9.38
4	6.02	6.10	6.58	7.28	8.63	8.89	8.84	8.84
5	6.02	6.10	6.58	7.28	8.63	8.89	8.84	8.84
6	6.02	6.10	6.58	7.28	8.63	8.89	8.84	8.84
7	6.02	6.10	6.58	7.28	8.63	8.89	8.84	8.84
8	6.02	6.02	6.02	6.02	6.02	6.02	6.02	6.02
9	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00

Grid line	9	10	11	12	13	14	15	16
X-Coord	35.44	35.54	36.54	36.64	39.31	39.63	46.44	50.00
Stratum	Y-Coordinates							
1(GL)	9.36	9.36	9.35	9.35	9.80	9.85	11.00	13.00
2	9.36	9.36	9.35	9.35	9.09	9.06	7.76	7.13
3	9.36	9.36	9.35	9.35	8.86	8.86	7.56	6.93
4	8.84	7.83	7.83	8.78	8.85	8.85	7.55	6.92
5	8.84	7.82	7.82	8.73	8.84	8.84	7.54	6.91
6	8.84	7.82	7.82	8.68	8.39	8.33	7.03	6.48
7	8.84	7.81	7.81	8.62	8.38	8.33	7.03	6.47
8	6.02	6.02	6.02	6.02	6.02	6.02	6.02	6.02
9	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00

Grid line	17	18	19	20	21	22	23	24
X-Coord	59.46	61.83	63.06	63.08	69.03	73.57	75.33	82.47
Stratum	Y-Coordinates							
1(GL)	15.41	16.01	16.32	16.33	17.84	19.00	19.34	20.74
2	5.47	5.14	4.17	4.17	3.48	3.64	4.00	4.00
3	5.27	4.88	3.97	3.97	3.28	3.44	3.80	3.80
4	5.26	4.87	3.96	3.96	3.28	3.44	3.79	3.79
5	5.25	4.87	3.96	3.96	3.28	3.44	3.79	3.79
6	5.00	4.87	3.96	3.96	3.28	3.44	3.79	3.79
7	4.99	4.86	3.95	3.96	3.28	3.44	3.79	3.79
8	4.99	4.86	3.95	3.96	3.28	3.44	3.79	3.79
9	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00

Piezometric surfaces associated with individual strata

Grid line	1	2	3	4	5	6	7	8
X-Coord	0.00	9.14	20.88	23.19	29.82	32.41	33.64	34.53
Surface	Piezometric elevation							
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00

Grid line	9	10	11	12	13	14	15	16
X-Coord	35.44	35.54	36.54	36.64	39.31	39.63	46.44	50.00
Surface	Piezometric elevation							
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00

Grid line	17	18	19	20	21	22	23	24
X-Coord	59.46	61.83	63.06	63.08	69.03	73.57	75.33	82.47
Surface	Piezometric elevation							
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00

Grid line	25
X-Coord	135.00
Surface	Piezometric elevation
2	0.00
3	7.00

CIRCULAR SLIP SURFACE DATA

Grid of centres:	X	Y
Corner of grid	40.00	30.00
Grid increment	2.00	2.00
No. of grid lines	5	5

The grid of centres will be extended automatically
until a minimum factor of safety has been found.

Common point(s):	X	Y
Coordinates of (first) point	20.88	6.58
Increment between points	5.00	0.00

Number of points = 5

ANALYSIS OPTIONS

Method of analysis: BISHOP - Simplified : Horizontal interslice forces
Factors of safety calculated on Soil Strength
Partial factor of safety on tan(phi) = 1.000
Partial factor of safety on drained cohesion = 1.000
Partial factor of safety on undrained cohesion = 1.000
Partial factor of safety on soil weight = 1.000
Partial factor of safety on surcharge loads = 1.000
Minimum number of slices = 10

PROFILE DATA (continued)

Grid line 25
X-Coord 135.00

Stratum	Y-Coordinates
1(GL)	31.00
2	3.98
3	3.78
4	3.77
5	3.77
6	3.77
7	3.77
8	3.77
9	-3.00

SOIL PROPERTIES

--- Stratum --- No.	Description	Bulk unit wt. below GWL KN/M3	Bulk unit wt. above GWL KN/M3	Strength parameters C KN/M2	Phi (deg)	dC/dY KN/M2/M	Datum for C
1	WASTE	11.00	11.00	0.00	27.00	Piezometric surface 3	
2	DRAINAGE STONE	18.00	18.00	0.00	33.00		
3	CLAY COVER	18.00	18.00	25.00	0.00		
4	HDPE/ABTEX	10.00	10.00	0.00	6.00		
5	COMPACTED CLAY	18.00	18.00	25.00	0.00		
6	GEOGRID	10.00	10.00	0.00	6.00		
7	CLAY BUND	18.00	18.00	25.00	0.00		
8	ALLUVIUM	18.00	18.00	6.00	0.00	13.00	6.02
9	GRAVEL	20.00	20.00	0.00	45.00	Piezometric surface 2	

GROUND WATER CONDITIONS

Unit wt. of water = 9.81 KN/M3

Grid line	1	2	3	4	5	6	7	8
X-Coord	0.00	9.14	20.88	23.19	29.82	32.41	33.64	34.53
Ground water level	6.02	6.02	6.02	6.02	6.02	6.02	6.02	6.02

Grid line	9	10	11	12	13	14	15	16
X-Coord	35.44	35.54	36.54	36.64	39.31	39.63	46.44	50.00
Ground water level	6.02	6.02	6.02	6.02	6.02	6.02	6.02	6.02

Grid line	17	18	19	20	21	22	23	24
X-Coord	59.46	61.83	63.06	63.08	69.03	73.57	75.33	82.47
Ground water level	6.02	6.02	6.02	6.02	6.02	6.02	6.02	6.02

Grid line	25
X-Coord	135.00
Ground water level	6.02

KENNEDY AND DONKIN LTD

Program: SLOPE Version 9R.01 Revision A01.B01.R19
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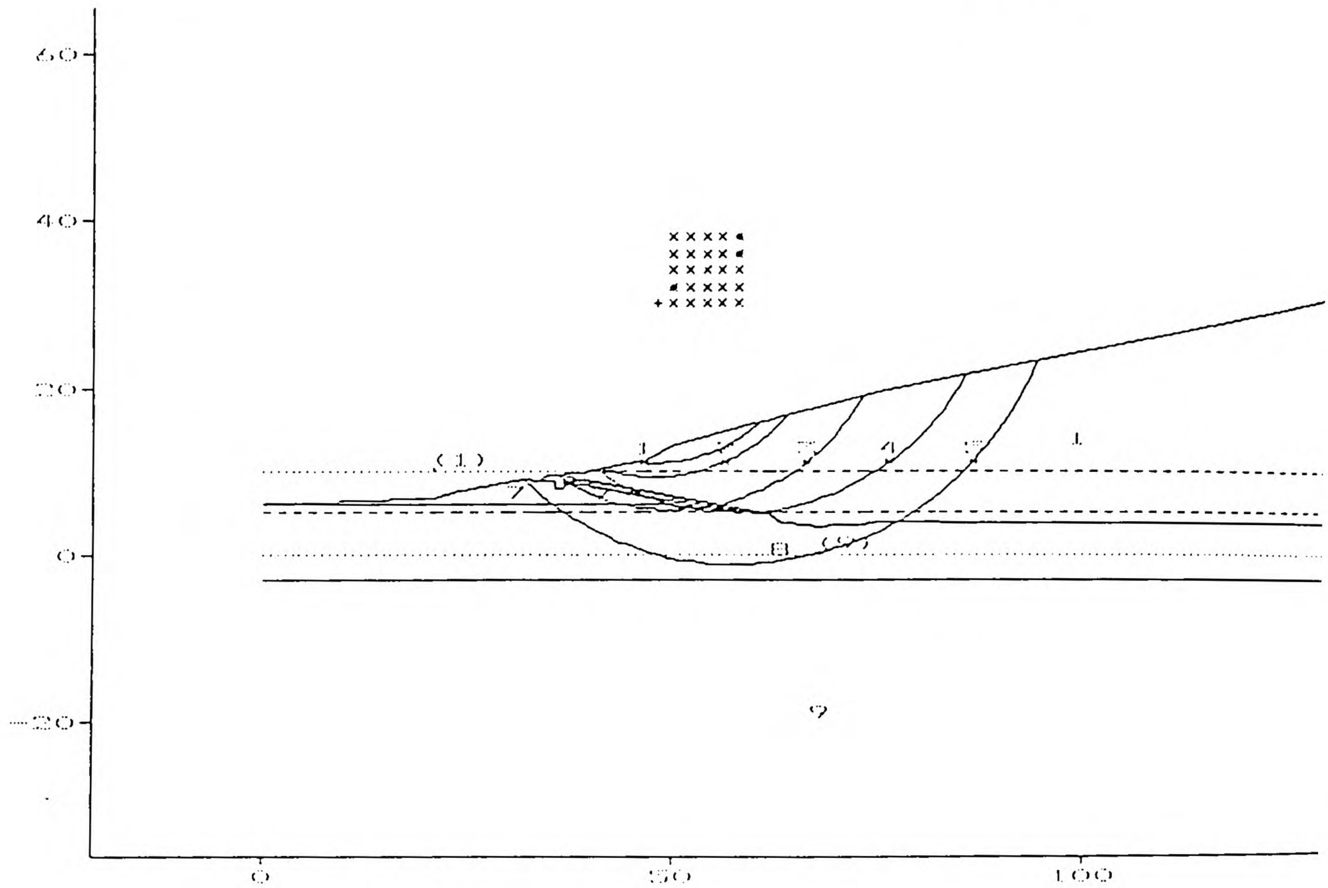
[redacted] Eastern Extension
Section F east slope lower range high leachate

| Sheet No.
| Run No. FCRPLBA
|
| Job No. 026
| Made by : DJG
| Date: 4-03-1999
| Checked :

Units: KN,M



Scale = 1 : 913

---- Common point -----			----------- Critical circle ---------			
			---- Centre ----			
Point no.	X coord	Y coord	X	Y	Radius	Factor of safety
1	46.44	11.00	48.00	30.00	19.06	1.272
2	56.44	11.00	48.00	30.00	20.79	1.283
3	66.44	11.00	50.00	32.00	26.67	1.190
4	76.44	11.00	58.00	36.00	31.06	1.293
5	86.44	11.00	58.00	38.00	39.22	2.316

KENNEDY AND DONKIN LTD | Sheet No.
| Run No. FCRPLBA

Program: SLOPE Version 9R.01 Revision A01.B01.R19
Licensed from GEOSOLVE | Job No. 026
| Made by : DJG
[redacted] Eastern Extension | Date: 4-03-1999
Section F east slope lower range high leachate | Checked :

Units: KN,M

INPUT DATA

PROFILE DATA

Grid line	1	2	3	4	5	6	7	8
X-Coord	0.00	9.14	20.88	23.19	29.82	32.41	33.64	34.53
Stratum	Y-Coordinates							
1(GL)	6.02	6.10	6.58	7.28	8.63	8.89	8.84	9.38
2	6.02	6.10	6.58	7.28	8.63	8.89	8.84	9.38
3	6.02	6.10	6.58	7.28	8.63	8.89	8.84	9.38
4	6.02	6.10	6.58	7.28	8.63	8.89	8.84	8.84
5	6.02	6.10	6.58	7.28	8.63	8.89	8.84	8.84
6	6.02	6.10	6.58	7.28	8.63	8.89	8.84	8.84
7	6.02	6.10	6.58	7.28	8.63	8.89	8.84	8.84
8	6.02	6.02	6.02	6.02	6.02	6.02	6.02	6.02
9	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00

Grid line	9	10	11	12	13	14	15	16
X-Coord	35.44	35.54	36.54	36.64	39.31	39.63	46.44	50.00
Stratum	Y-Coordinates							
1(GL)	9.36	9.36	9.35	9.35	9.80	9.85	11.00	13.00
2	9.36	9.36	9.35	9.35	9.09	9.06	7.76	7.13
3	9.36	9.36	9.35	9.35	8.86	8.86	7.56	6.93
4	8.84	7.83	7.83	8.78	8.85	8.85	7.55	6.92
5	8.84	7.82	7.82	8.73	8.84	8.84	7.54	6.91
6	8.84	7.82	7.82	8.68	8.39	8.33	7.03	6.48
7	8.84	7.81	7.81	8.62	8.38	8.33	7.03	6.47
8	6.02	6.02	6.02	6.02	6.02	6.02	6.02	6.02
9	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00

Grid line	17	18	19	20	21	22	23	24
X-Coord	59.46	61.83	63.06	63.08	69.03	73.57	75.33	82.47
Stratum	Y-Coordinates							
1(GL)	15.41	16.01	16.32	16.33	17.84	19.00	19.34	20.74
2	5.47	5.14	4.17	4.17	3.48	3.64	4.00	4.00
3	5.27	4.88	3.97	3.97	3.28	3.44	3.80	3.80
4	5.26	4.87	3.96	3.96	3.28	3.44	3.79	3.79
5	5.25	4.87	3.96	3.96	3.28	3.44	3.79	3.79
6	5.00	4.87	3.96	3.96	3.28	3.44	3.79	3.79
7	4.99	4.86	3.95	3.96	3.28	3.44	3.79	3.79
8	4.99	4.86	3.95	3.96	3.28	3.44	3.79	3.79
9	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00

PROFILE DATA (continued)

Grid line 25
X-Coord 135.00

Stratum	Y-Coordinates
1(GL)	31.00
2	3.98
3	3.78
4	3.77
5	3.77
6	3.77
7	3.77
8	3.77
9	-3.00

SOIL PROPERTIES

--- Stratum --- No.	Description	Bulk unit wt. below GWL KN/M3	above GWL KN/M3	Strength parameters C KN/M2	Phi (deg)	dC/dY KN/M2/M	Datum for C
1	WASTE	15.00	15.00	0.00	20.00	Piezometric surface 4	
2	DRAINAGE STONE	18.00	18.00	0.00	16.00		
3	CLAY COVER	20.00	20.00	15.00	0.00		
4	HDPE/ABTEX	10.00	10.00	0.00	6.00		
5	COMPACTED CLAY	20.00	20.00	15.00	0.00		
6	GEOGRID	10.00	10.00	0.00	6.00		
7	CLAY BUND	20.00	20.00	15.00	0.00		
8	ALLUVIUM	18.00	18.00	6.00	0.00	13.00	6.02
9	GRAVEL	20.00	20.00	0.00	30.00	Piezometric surface 2	

GROUND WATER CONDITIONS

Unit wt. of water = 9.81 KN/M3

Grid line	1	2	3	4	5	6	7	8
X-Coord	0.00	9.14	20.88	23.19	29.82	32.41	33.64	34.53
Ground water level	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00

Grid line	9	10	11	12	13	14	15	16
X-Coord	35.44	35.54	36.54	36.64	39.31	39.63	46.44	50.00
Ground water level	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00

Grid line	17	18	19	20	21	22	23	24
X-Coord	59.46	61.83	63.06	63.08	69.03	73.57	75.33	82.47
Ground water level	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00

Grid line	25
X-Coord	135.00
Ground water level	5.00

Piezometric surfaces associated with individual strata

Grid line	1	2	3	4	5	6	7	8
X-Coord	0.00	9.14	20.88	23.19	29.82	32.41	33.64	34.53
Surface	Piezometric elevation							
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00

Grid line	9	10	11	12	13	14	15	16
X-Coord	35.44	35.54	36.54	36.64	39.31	39.63	46.44	50.00
Surface	Piezometric elevation							
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00

Grid line	17	18	19	20	21	22	23	24
X-Coord	59.46	61.83	63.06	63.08	69.03	73.57	75.33	82.47
Surface	Piezometric elevation							
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00

Grid line	25
X-Coord	135.00
Surface	Piezometric elevation
2	0.00
4	10.00

CIRCULAR SLIP SURFACE DATA

Grid of centres:	X	Y
Corner of grid	50.00	30.00
Grid increment	2.00	2.00
No. of grid lines	5	5

The grid of centres will be extended automatically
until a minimum factor of safety has been found.

Common point(s):	X	Y
Coordinates of (first) point	46.44	11.00
Increment between points	10.00	0.00

Number of points = 5

ANALYSIS OPTIONS

Method of analysis: BISHOP - Simplified : Horizontal interslice forces
Factors of safety calculated on Soil Strength
Partial factor of safety on tan(phi) = 1.000
Partial factor of safety on drained cohesion = 1.000
Partial factor of safety on undrained cohesion = 1.000
Partial factor of safety on soil weight = 1.000
Partial factor of safety on surcharge loads = 1.000
Minimum number of slices = 10

KENNEDY AND DONKIN LTD

Program: SLOPE Version 9R.01 Revision A01.B01.R19
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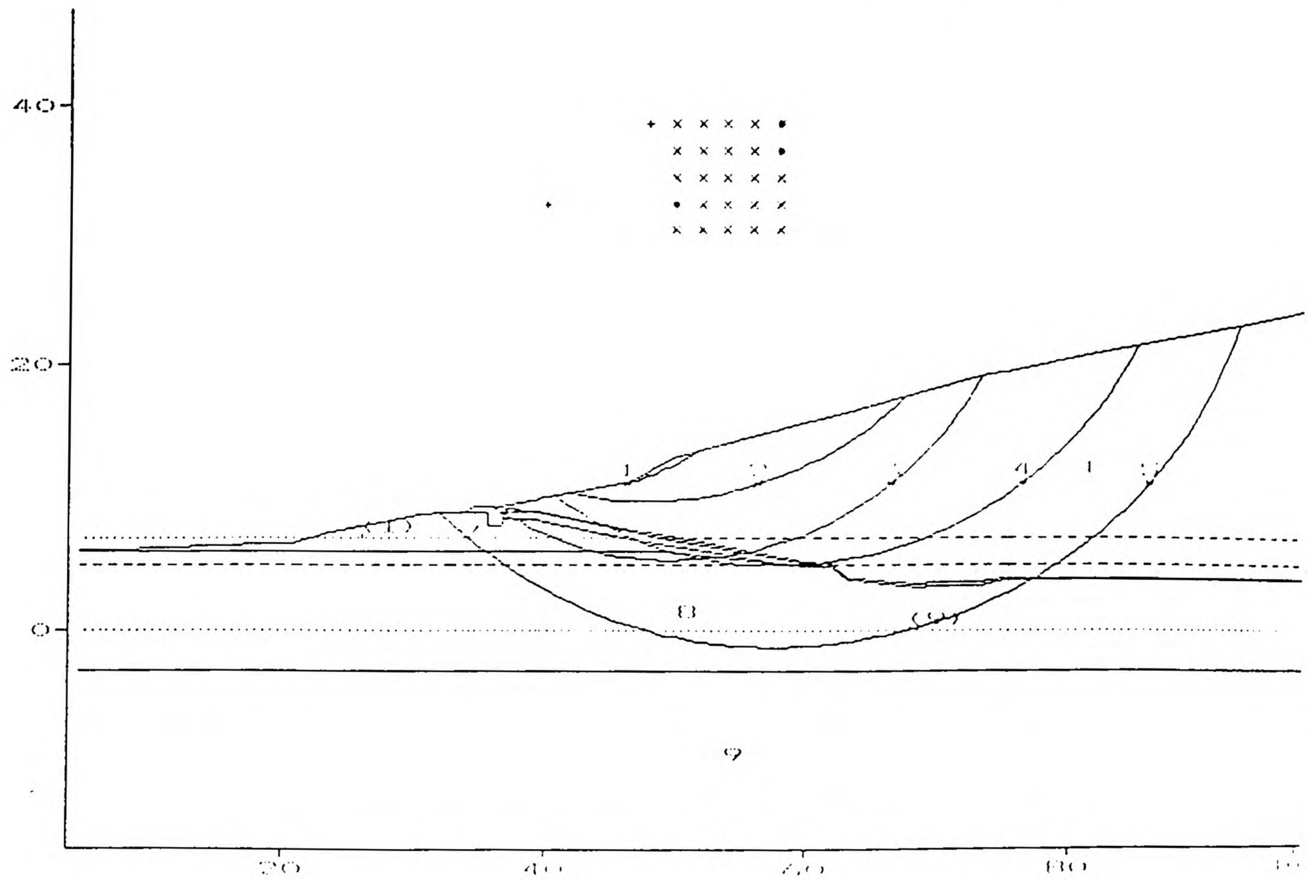
[redacted] SLOPE STABILITY
SECTION F

| Sheet No.
| Run No. FCRPLB
|
| Job No. 026
| Made by : GJ
| Date: 18-02-1999
| Checked :

Units: KN,M



Scale = 1 : 571

---- Common point -----			----------- Critical circle ---------			
Point no.	X coord	Y coord	---- Centre ---- X	Y	Radius	Factor of safetv
1	46.44	11.00	40.00	32.00	21.97	0.783
2	56.44	11.00	48.00	38.00	28.29	1.368
3	66.44	11.00	50.00	32.00	26.67	1.300
4	76.44	11.00	58.00	36.00	31.06	1.417
5	86.44	11.00	58.00	38.00	39.22	2.343

KENNEDY AND DONKIN LTD

Program: SLOPE Version 9R.01 Revision A01.B01.R19
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[redacted] SLOPE STABILITY
SECTION F

Sheet No.	
Run No.	FCRPLB
Job No.	026
Made by :	GJ
Date:	18-02-1999
Checked :	

Units: KN,M

INPUT DATA

PROFILE DATA

Grid line	1	2	3	4	5	6	7	8
X-Coord	0.00	9.14	20.88	23.19	29.82	32.41	33.64	34.53
Stratum	Y-Coordinates							
1(GL)	6.02	6.10	6.58	7.28	8.63	8.89	8.84	9.38
2	6.02	6.10	6.58	7.28	8.63	8.89	8.84	9.38
3	6.02	6.10	6.58	7.28	8.63	8.89	8.84	9.38
4	6.02	6.10	6.58	7.28	8.63	8.89	8.84	8.84
5	6.02	6.10	6.58	7.28	8.63	8.89	8.84	8.84
6	6.02	6.10	6.58	7.28	8.63	8.89	8.84	8.84
7	6.02	6.10	6.58	7.28	8.63	8.89	8.84	8.84
8	6.02	6.02	6.02	6.02	6.02	6.02	6.02	6.02
9	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00

Grid line	9	10	11	12	13	14	15	16
X-Coord	35.44	35.54	36.54	36.64	39.31	39.63	46.44	50.00
Stratum	Y-Coordinates							
1(GL)	9.36	9.36	9.35	9.35	9.80	9.85	11.00	13.00
2	9.36	9.36	9.35	9.35	9.09	9.06	7.76	7.13
3	9.36	9.36	9.35	9.35	8.86	8.86	7.56	6.93
4	8.84	7.83	7.83	8.78	8.85	8.85	7.55	6.92
5	8.84	7.82	7.82	8.73	8.84	8.84	7.54	6.91
6	8.84	7.82	7.82	8.68	8.39	8.33	7.03	6.48
7	8.84	7.81	7.81	8.62	8.38	8.33	7.03	6.47
8	6.02	6.02	6.02	6.02	6.02	6.02	6.02	6.02
9	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00

Grid line	17	18	19	20	21	22	23	24
X-Coord	59.46	61.83	63.06	63.08	69.03	73.57	75.33	82.47
Stratum	Y-Coordinates							
1(GL)	15.41	16.01	16.32	16.33	17.84	19.00	19.34	20.74
2	5.47	5.14	4.17	4.17	3.48	3.64	4.00	4.00
3	5.27	4.88	3.97	3.97	3.28	3.44	3.80	3.80
4	5.26	4.87	3.96	3.96	3.28	3.44	3.79	3.79
5	5.25	4.87	3.96	3.96	3.28	3.44	3.79	3.79
6	5.00	4.87	3.96	3.96	3.28	3.44	3.79	3.79
7	4.99	4.86	3.95	3.96	3.28	3.44	3.79	3.79
8	4.99	4.86	3.95	3.96	3.28	3.44	3.79	3.79
9	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00

PROFILE DATA (continued)

Grid line 25
X-Coord 135.00

Stratum	Y-Coordinates
1(GL)	31.00
2	3.98
3	3.78
4	3.77
5	3.77
6	3.77
7	3.77
8	3.77
9	-3.00

SOIL PROPERTIES

--- Stratum ---		Bulk unit wt.		-------Strength parameters------			
No.	Description	below GWL KN/M3	above GWL KN/M3	C KN/M2	Phi (deg)	dC/dY KN/M2/M	Datum for C
1	WASTE	15.00	15.00	0.00	20.00	Piezometric surface 4	
2	DRAINAGE STONE	18.00	18.00	0.00	16.00		
3	CLAY COVER	20.00	20.00	15.00	0.00		
4	HDPE/ABTEX	10.00	10.00	0.00	6.00		
5	COMPACTED CLAY	20.00	20.00	15.00	0.00		
6	GEOGRID	10.00	10.00	0.00	6.00		
7	CLAY BUND	20.00	20.00	15.00	0.00		
8	ALLUVIUM	18.00	18.00	6.00	0.00	13.00	6.02
9	GRAVEL	20.00	20.00	0.00	30.00	Piezometric surface 2	

GROUND WATER CONDITIONS

Unit wt. of water = 9.81 KN/M3

Grid line	1	2	3	4	5	6	7	8
X-Coord	0.00	9.14	20.88	23.19	29.82	32.41	33.64	34.53
Ground water level	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00

Grid line	9	10	11	12	13	14	15	16
X-Coord	35.44	35.54	36.54	36.64	39.31	39.63	46.44	50.00
Ground water level	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00

Grid line	17	18	19	20	21	22	23	24
X-Coord	59.46	61.83	63.06	63.08	69.03	73.57	75.33	82.47
Ground water level	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00

Grid line	25
X-Coord	135.00
Ground water level	5.00

KENNEDY AND DONKIN LTD

Program: SLOPE Version 9R.01 Revision A01.B01.R19
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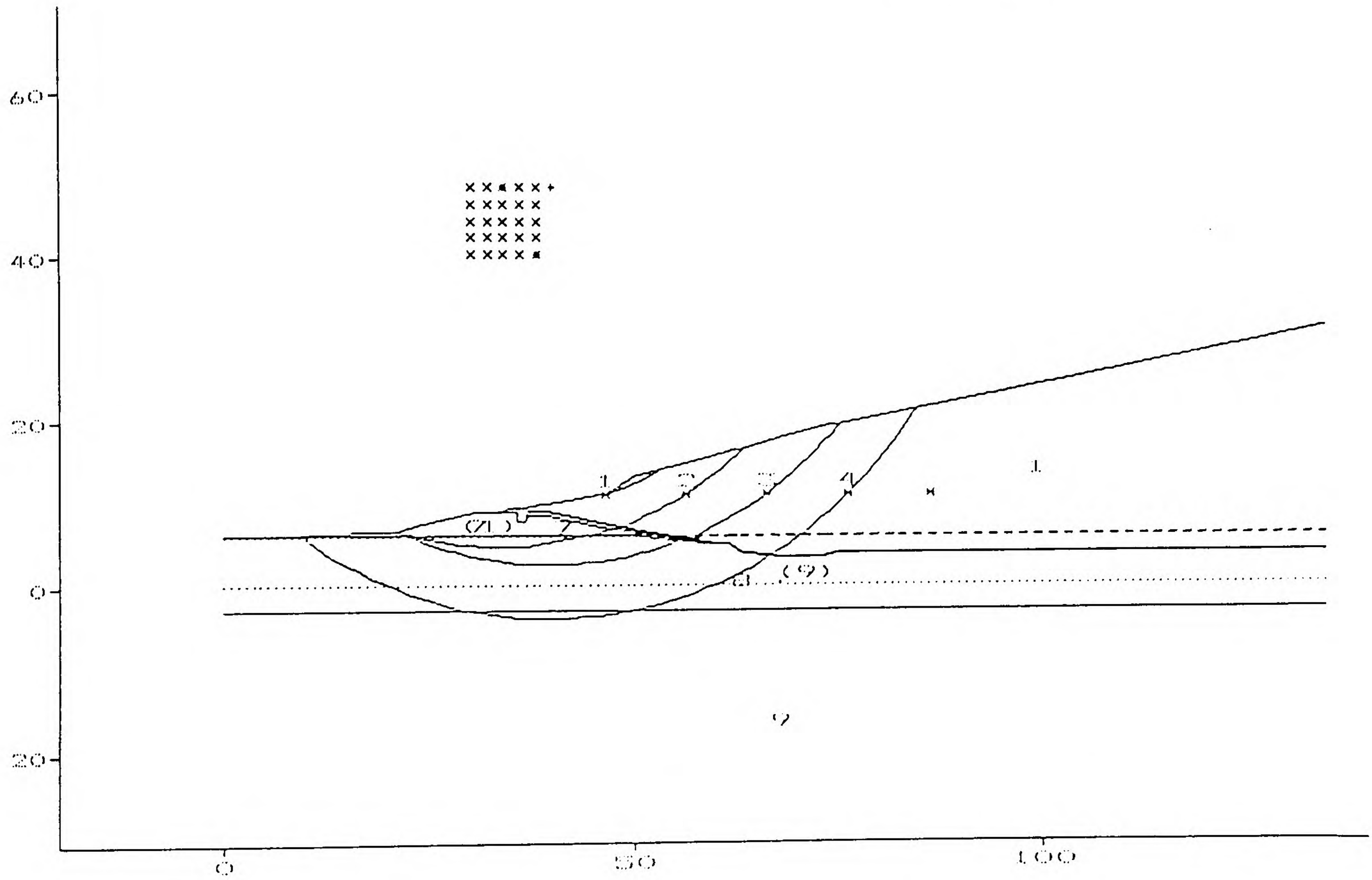
[redacted] Eastern Extension
Section F Eastern slope upper range parameters

| Sheet No.
| Run No. FCRPUB
|
| Job No. 026
| Made by : DJG
| Date: 4-03-1999
| Checked :

Units: KN,M



Scale = 1 : 913

---- Common point -----			---------- Critical circle ---------			
Point no.	X coord	Y coord	---- Centre ---- X	Y	Radius	Factor of safety
1	46.44	11.00	38.00	40.00	30.20	1.207
2	56.44	11.00	34.00	48.00	43.27	2.266
3	66.44	11.00	40.00	48.00	45.48	2.701
4	76.44	11.00	40.00	48.00	51.93	5.294
5	86.44	11.00	-	-	-	-

KENNEDY AND DONKIN LTD

Program: SLOPE Version 9R.01 Revision A01.B01.R19
Licensed from GEOSOLVE

[redacted] Eastern Extension
Section F Eastern slope upper range parameters

| Sheet No. |
| Run No. FCRPUB |
| Job No. 026 |
| Made by : DJG |
| Date: 4-03-1999 |
| Checked : |

Units: KN,M

INPUT DATA

PROFILE DATA

Grid line	1	2	3	4	5	6	7	8
X-Coord	0.00	9.14	20.88	23.19	29.82	32.41	33.64	34.53
Stratum	Y-Coordinates							
1(GL)	6.02	6.10	6.58	7.28	8.63	8.89	8.84	9.38
2	6.02	6.10	6.58	7.28	8.63	8.89	8.84	9.38
3	6.02	6.10	6.58	7.28	8.63	8.89	8.84	9.38
4	6.02	6.10	6.58	7.28	8.63	8.89	8.84	8.84
5	6.02	6.10	6.58	7.28	8.63	8.89	8.84	8.84
6	6.02	6.10	6.58	7.28	8.63	8.89	8.84	8.84
7	6.02	6.10	6.58	7.28	8.63	8.89	8.84	8.84
8	6.02	6.02	6.02	6.02	6.02	6.02	6.02	6.02
9	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00

Grid line	9	10	11	12	13	14	15	16
X-Coord	35.44	35.54	36.54	36.64	39.31	39.63	46.44	50.00
Stratum	Y-Coordinates							
1(GL)	9.36	9.36	9.35	9.35	9.80	9.85	11.00	13.00
2	9.36	9.36	9.35	9.35	9.09	9.06	7.76	7.13
3	9.36	9.36	9.35	9.35	8.86	8.86	7.56	6.93
4	8.84	7.83	7.83	8.78	8.85	8.85	7.55	6.92
5	8.84	7.82	7.82	8.73	8.84	8.84	7.54	6.91
6	8.84	7.82	7.82	8.68	8.39	8.33	7.03	6.48
7	8.84	7.81	7.81	8.62	8.38	8.33	7.03	6.47
8	6.02	6.02	6.02	6.02	6.02	6.02	6.02	6.02
9	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00

Grid line	17	18	19	20	21	22	23	24
X-Coord	59.46	61.83	63.06	63.08	69.03	73.57	75.33	82.47
Stratum	Y-Coordinates							
1(GL)	15.41	16.01	16.32	16.33	17.84	19.00	19.34	20.74
2	5.47	5.14	4.17	4.17	3.48	3.64	4.00	4.00
3	5.27	4.88	3.97	3.97	3.28	3.44	3.80	3.80
4	5.26	4.87	3.96	3.96	3.28	3.44	3.79	3.79
5	5.25	4.87	3.96	3.96	3.28	3.44	3.79	3.79
6	5.00	4.87	3.96	3.96	3.28	3.44	3.79	3.79
7	4.99	4.86	3.95	3.96	3.28	3.44	3.79	3.79
8	4.99	4.86	3.95	3.96	3.28	3.44	3.79	3.79
9	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00

PROFILE DATA (continued)

Grid line 25
X-Coord 135.00

Stratum	Y-Coordinates
1(GL)	31.00
2	3.98
3	3.78
4	3.77
5	3.77
6	3.77
7	3.77
8	3.77
9	-3.00

SOIL PROPERTIES

--- Stratum --- No.	Description	Bulk unit wt. below GWL KN/M3	Bulk unit wt. above GWL KN/M3	Strength parameters C KN/M2	Phi (deg)	dC/dY KN/M2/M	Datum for C
1	WASTE	11.00	11.00	0.00	27.00	Piezometric surface 1	
2	DRAINAGE STONE	18.00	18.00	0.00	33.00		
3	CLAY COVER	18.00	18.00	25.00	0.00		
4	HDPE/ABTEX	10.00	10.00	0.00	8.00		
5	COMPACTED CLAY	18.00	18.00	25.00	0.00		
6	GEOGRID	10.00	10.00	0.00	8.00		
7	CLAY BUND	18.00	18.00	25.00	0.00		
8	ALLUVIUM	18.00	18.00	6.00	0.00	13.00	6.02
9	GRAVEL	20.00	20.00	0.00	45.00	Piezometric surface 2	

GROUND WATER CONDITIONS

Unit wt. of water = 9.81 KN/M3

Grid line	1	2	3	4	5	6	7	8
X-Coord	0.00	9.14	20.88	23.19	29.82	32.41	33.64	34.53
Ground water level	6.02	6.02	6.02	6.02	6.02	6.02	6.02	6.02

Grid line	9	10	11	12	13	14	15	16
X-Coord	35.44	35.54	36.54	36.64	39.31	39.63	46.44	50.00
Ground water level	6.02	6.02	6.02	6.02	6.02	6.02	6.02	6.02

Grid line	17	18	19	20	21	22	23	24
X-Coord	59.46	61.83	63.06	63.08	69.03	73.57	75.33	82.47
Ground water level	6.02	6.02	6.02	6.02	6.02	6.02	6.02	6.02

Grid line	25
X-Coord	135.00
Ground water level	6.02

Piezometric surfaces associated with individual strata

Grid line	1	2	3	4	5	6	7	8
X-Coord	0.00	9.14	20.88	23.19	29.82	32.41	33.64	34.53
Surface	Piezometric elevation							
1	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Grid line	9	10	11	12	13	14	15	16
X-Coord	35.44	35.54	36.54	36.64	39.31	39.63	46.44	50.00
Surface	Piezometric elevation							
1	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Grid line	17	18	19	20	21	22	23	24
X-Coord	59.46	61.83	63.06	63.08	69.03	73.57	75.33	82.47
Surface	Piezometric elevation							
1	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Grid line	25
X-Coord	135.00
Surface	Piezometric elevation
1	6.00
2	0.00

CIRCULAR SLIP SURFACE DATA

Grid of centres:	X	Y
Corner of grid	30.00	40.00
Grid increment	2.00	2.00
No. of grid lines	5	5

The grid of centres will be extended automatically
until a minimum factor of safety has been found.

Common point(s):	X	Y
Coordinates of (first) point	46.44	11.00
Increment between points	10.00	0.00

Number of points = 5

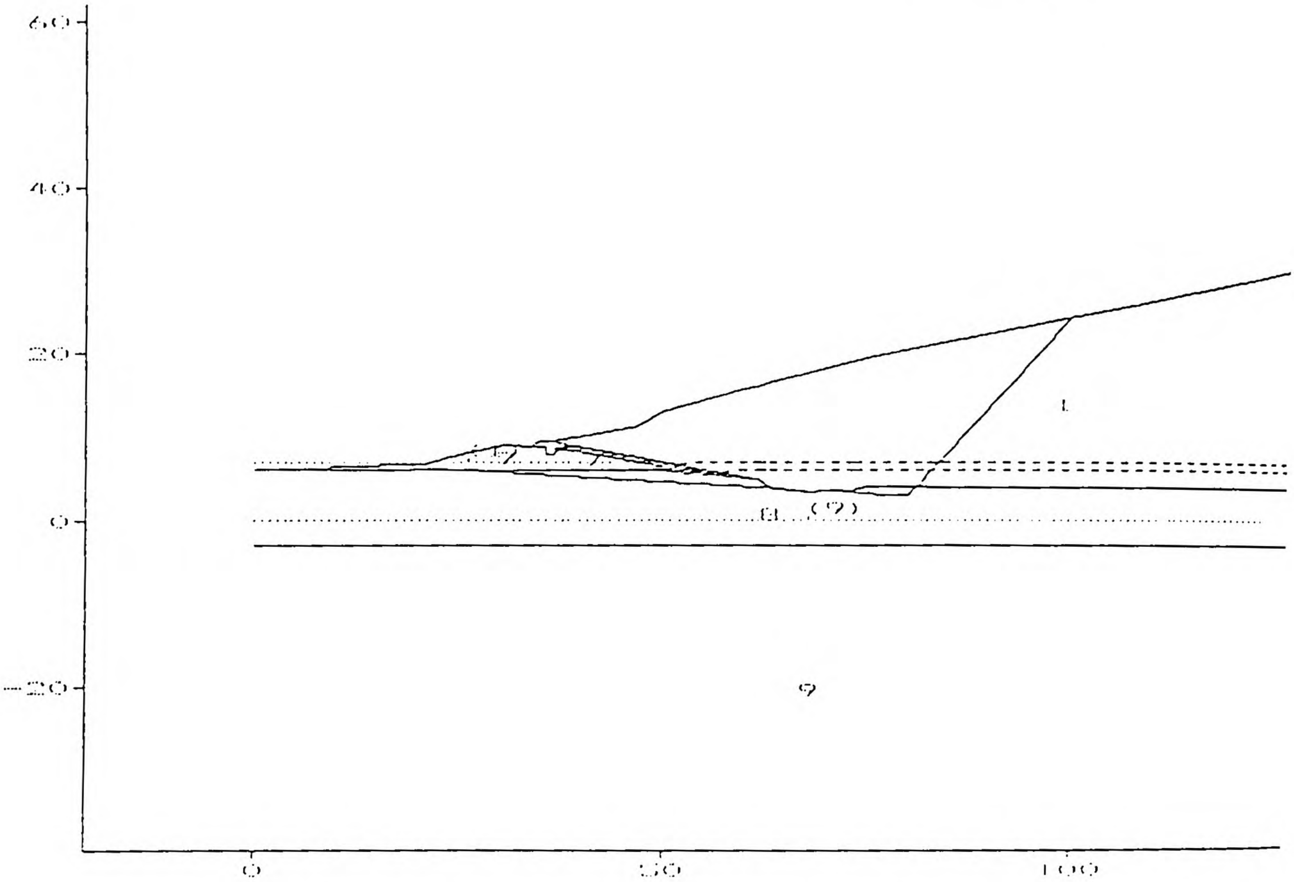
ANALYSIS OPTIONS

Method of analysis: BISHOP - Simplified : Horizontal interslice forces
Factors of safety calculated on Soil Strength
Partial factor of safety on tan(phi) = 1.000
Partial factor of safety on drained cohesion = 1.000
Partial factor of safety on undrained cohesion = 1.000
Partial factor of safety on soil weight = 1.000
Partial factor of safety on surcharge loads = 1.000
Minimum number of slices = 10

APPENDIX 6 EASTERN BUND - ANALYSIS FOR NON CIRCULAR FAILURE POST RESTORATION

KENNEDY AND DONKIN LTD | Sheet No.
| Run No. FNBLB
Program: SLOPE Version 9R.01 Revision A01.B01.R19 |
Licensed from GEOSOLVE | Job No. 026
| Made by : DJG
[redacted] Eastern Extension | Date: 4-03-1999
Section F Eastern Bund lower range parameters | Checked :

Units: KN,M



Scale = 1 : 913

Factor of safety = 1.393

KENNEDY AND DONKIN LTD | Sheet No.
| Run No. FNBL3

Program: SLOPE Version 9R.01 Revision A01.B01.R19 |
Licensed from GEOSOLVE | Job No. 026
| Made by : DJG
[redacted]y Eastern Extension | Date: 4-03-1999
Section F Eastern Bund lower range parameters | Checked :

Units: KN,M

INPUT DATA

PROFILE DATA

Grid line	1	2	3	4	5	6	7	8
X-Coord	0.00	9.14	20.88	23.19	29.32	32.41	33.64	34.53
Stratum	Y-Coordinates							
1(GL)	6.02	6.10	6.58	7.28	8.63	8.89	8.84	9.38
2	6.02	6.10	6.58	7.28	8.63	8.89	8.84	9.38
3	6.02	6.10	6.58	7.28	8.63	8.89	8.84	9.38
4	6.02	6.10	6.58	7.28	8.63	8.89	8.84	8.84
5	6.02	6.10	6.58	7.28	8.63	8.89	8.84	8.84
6	6.02	6.10	6.58	7.28	8.63	8.89	8.84	8.84
7	6.02	6.10	6.58	7.28	8.63	8.89	8.84	8.84
8	6.02	6.02	6.02	6.02	6.02	6.02	6.02	6.02
9	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00

Grid line	9	10	11	12	13	14	15	16
X-Coord	35.44	35.54	36.54	36.64	39.31	39.63	46.44	50.00
Stratum	Y-Coordinates							
1(GL)	9.36	9.36	9.35	9.35	9.80	9.85	11.00	13.00
2	9.36	9.36	9.35	9.35	9.09	9.06	7.76	7.13
3	9.36	9.36	9.35	9.35	8.86	8.86	7.56	6.93
4	8.84	7.83	7.83	8.78	8.85	8.85	7.55	6.92
5	8.84	7.82	7.82	8.73	8.84	8.84	7.54	6.91
6	8.84	7.82	7.82	8.68	8.39	8.33	7.03	6.48
7	8.84	7.81	7.81	8.62	8.38	8.33	7.03	6.47
8	6.02	6.02	6.02	6.02	6.02	6.02	6.02	6.02
9	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00

Grid line	17	18	19	20	21	22	23	24
X-Coord	59.46	61.83	63.06	63.08	69.03	73.57	75.33	82.47
Stratum	Y-Coordinates							
1(GL)	15.41	16.01	16.32	16.33	17.34	19.00	19.34	20.74
2	5.47	5.14	4.17	4.17	3.48	3.64	4.00	4.00
3	5.27	4.88	3.97	3.97	3.28	3.44	3.80	3.80
4	5.26	4.87	3.96	3.96	3.28	3.44	3.79	3.79
5	5.25	4.87	3.96	3.96	3.28	3.44	3.79	3.79
6	5.00	4.87	3.96	3.96	3.28	3.44	3.79	3.79
7	4.99	4.86	3.95	3.96	3.28	3.44	3.79	3.79
8	4.99	4.86	3.95	3.96	3.28	3.44	3.79	3.79
9	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00

PROFILE DATA (continued)

Grid line 25
X-Coord 135.00

Stratum	Y-Coordinates
1(GL)	31.00
2	3.98
3	3.78
4	3.77
5	3.77
6	3.77
7	3.77
8	3.77
9	-3.00

SOIL PROPERTIES

--- Stratum --- No.	Description	Bulk unit wt. below GWL KN/M3	Bulk unit wt. above GWL KN/M3	Strength parameters C KN/M2	Phi (deg)	dC/dY KN/M2/M	Datum for C
1	WASTE	15.00	15.00	0.00	20.00	Piezometric surface 3	
2	DRAINAGE STONE	20.00	20.00	0.00	16.00		
3	CLAY COVER	20.00	20.00	8.00	0.00		
4	HDPE/ABTEX	10.00	10.00	0.00	6.00		
5	COMPACTED CLAY	20.00	20.00	15.00	0.00		
6	GEOGRID	10.00	10.00	0.00	5.00		
7	CLAY BUND	20.00	20.00	15.00	0.00		
8	ALLUVIUM	18.00	18.00	6.00	0.00	13.00	6.02
9	GRAVEL	20.00	20.00	0.00	30.00	Piezometric surface 2	

GROUND WATER CONDITIONS
Unit wt. of water = 9.81 KN/M3

Grid line	1	2	3	4	5	6	7	8
X-Coord	0.00	9.14	20.88	23.19	29.32	32.41	33.64	34.53
Ground water level	6.02	6.02	6.02	6.02	6.02	6.02	6.02	6.02

Grid line	9	10	11	12	13	14	15	16
X-Coord	35.44	35.54	36.54	36.64	39.31	39.53	46.44	50.00
Ground water level	6.02	6.02	6.02	6.02	6.02	6.02	6.02	6.02

Grid line	17	18	19	20	21	22	23	24
X-Coord	59.46	61.83	63.05	63.08	69.03	73.57	75.33	82.47
Ground water level	6.02	6.02	6.02	6.02	6.02	6.02	6.02	6.02

Grid line	25
X-Coord	135.00
Ground water level	6.02

Piezometric surfaces associated with individual strata

Grid line	1	2	3	4	5	6	7	8
X-Coord	0.00	9.14	20.88	23.19	29.32	32.41	33.64	34.53
Surface	Piezometric elevation							
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00

Grid line	9	10	11	12	13	14	15	16
X-Coord	35.44	35.54	36.54	36.64	39.31	39.63	46.44	50.00
Surface	Piezometric elevation							
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00

Grid line	17	18	19	20	21	22	23	24
X-Coord	59.46	61.83	63.06	63.08	69.03	73.57	75.33	82.47
Surface	Piezometric elevation							
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00

Grid line	25
X-Coord	135.00
Surface	Piezometric elevation
2	0.00
3	7.00

NON-CIRCULAR SLIP SURFACE DATA

Point no.	X Coord	Y Coord
1	19.00	6.50
2	80.00	3.00
3	100.00	24.16

ANALYSIS OPTIONS

Method of analysis: JANBU - Horizontal interslice forces
Factors of safety calculated on Soil Strength
Partial factor of safety on tan(phi) = 1.000
Partial factor of safety on drained cohesion = 1.000
Partial factor of safety on undrained cohesion = 1.000
Partial factor of safety on soil weight = 1.000
Partial factor of safety on surcharge loads = 1.000
Minimum number of slices = 10

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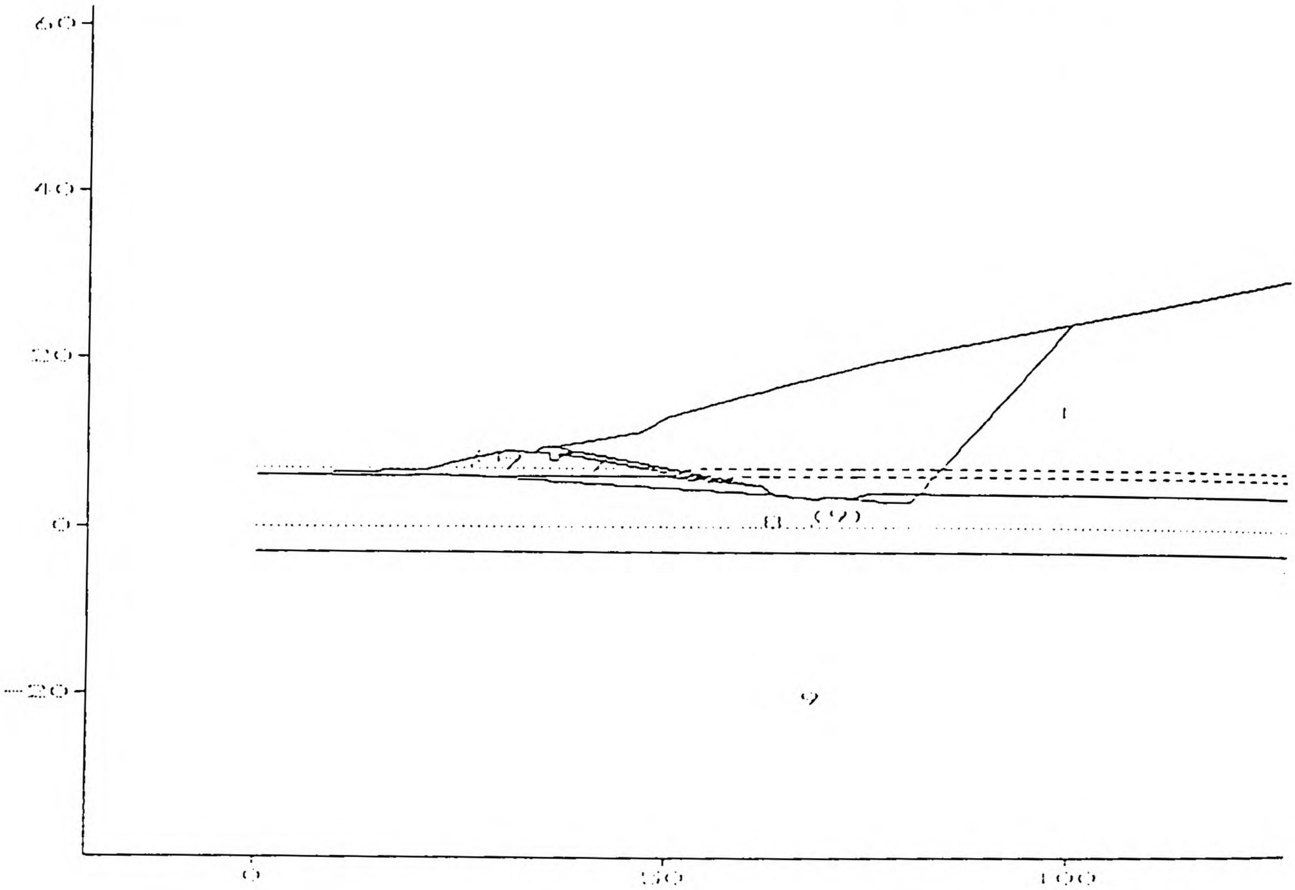
[redacted] Eastern Extension
Section F Eastern Bund non circular upper range

| Sheet No.
| Run No. FNBUB
|
| Job No. 026
| Made by : DJG
| Date: 4-03-1999
| Checked :

Units: KN,M



Scale = 1 : 913

Factor of safety = 2.206

KENNEDY AND DONKIN LTD

Program: SLOPE Version 9R.01 Revision A01.B01.R19
Licensed from GEOSOLVE

[redacted] Eastern Extension
Section F Eastern Bund non circular upper range

Sheet No.	
Run No.	FNBUB
Job No.	026
Made by :	DJG
Date:	4-03-1999
Checked :	

Units: KN,M

INPUT DATA

PROFILE DATA

Grid line	1	2	3	4	5	6	7	8
X-Coord	0.00	9.14	20.88	23.19	29.82	32.41	33.64	34.53
Stratum	Y-Coordinates							
1(GL)	6.02	6.10	6.58	7.28	8.63	8.89	8.84	9.38
2	6.02	6.10	6.58	7.28	8.63	8.89	8.84	9.38
3	6.02	6.10	6.58	7.28	8.63	8.89	8.84	9.38
4	6.02	6.10	6.58	7.28	8.63	8.89	8.84	8.84
5	6.02	6.10	6.58	7.28	8.63	8.89	8.84	8.84
6	6.02	6.10	6.58	7.28	8.63	8.89	8.84	8.84
7	6.02	6.10	6.58	7.28	8.63	8.89	8.84	8.84
8	6.02	6.02	6.02	6.02	6.02	6.02	6.02	6.02
9	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00

Grid line	9	10	11	12	13	14	15	16
X-Coord	35.44	35.54	36.54	36.64	39.31	39.63	46.44	50.00
Stratum	Y-Coordinates							
1(GL)	9.36	9.36	9.35	9.35	9.80	9.85	11.00	13.00
2	9.36	9.36	9.35	9.35	9.09	9.06	7.76	7.13
3	9.36	9.36	9.35	9.35	8.86	8.86	7.56	6.93
4	8.84	7.83	7.83	8.78	8.85	8.85	7.55	6.92
5	8.84	7.82	7.82	8.73	8.84	8.84	7.54	6.91
6	8.84	7.82	7.82	8.68	8.39	8.33	7.03	6.48
7	8.84	7.81	7.81	8.52	8.38	8.33	7.03	6.47
8	6.02	6.02	6.02	6.02	6.02	6.02	6.02	6.02
9	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00

Grid line	17	18	19	20	21	22	23	24
X-Coord	59.46	61.83	63.06	63.08	69.03	73.57	75.33	82.47
Stratum	Y-Coordinates							
1(GL)	15.41	16.01	16.32	16.33	17.84	19.00	19.34	20.74
2	5.47	5.14	4.17	4.17	3.48	3.64	4.00	4.00
3	5.27	4.88	3.97	3.97	3.28	3.44	3.80	3.80
4	5.26	4.87	3.96	3.96	3.28	3.44	3.79	3.79
5	5.25	4.87	3.96	3.96	3.28	3.44	3.79	3.79
6	5.00	4.87	3.96	3.96	3.28	3.44	3.79	3.79
7	4.99	4.86	3.95	3.96	3.28	3.44	3.79	3.79
8	4.99	4.86	3.95	3.96	3.28	3.44	3.79	3.79
9	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00

PROFILE DATA (continued)

Grid line 25
X-Coord 135.00

Stratum	Y-Coordinates
1(GL)	31.00
2	3.98
3	3.78
4	3.77
5	3.77
6	3.77
7	3.77
8	3.77
9	-3.00

SOIL PROPERTIES

--- Stratum --- No.	Description	Bulk unit wt. below GWL KN/M3	Bulk unit wt. above GWL KN/M3	Strength parameters C KN/M2	Phi (deg)	dC/dY KN/M2/M	Datum for C
1	WASTE	10.00	10.00	0.00	27.00	Piezometric surface 3	
2	DRAINAGE STONE	20.00	20.00	0.00	33.00		
3	CLAY COVER	20.00	20.00	25.00	0.00		
4	HDPE/ABTEX	10.00	10.00	0.00	6.00		
5	COMPACTED CLAY	20.00	20.00	25.00	0.00		
6	GEOGRID	10.00	10.00	0.00	5.00		
7	CLAY BUND	20.00	20.00	25.00	0.00		
8	ALLUVIUM	18.00	18.00	6.00	0.00	13.00	6.02
9	GRAVEL	20.00	20.00	0.00	45.00	Piezometric surface 2	

GROUND WATER CONDITIONS

Unit wt. of water = 9.81 KN/M3

Grid line	1	2	3	4	5	6	7	8
X-Coord	0.00	9.14	20.83	23.19	29.82	32.41	33.64	34.53
Ground water level	6.02	6.02	6.02	6.02	6.02	6.02	6.02	6.02

Grid line	9	10	11	12	13	14	15	16
X-Coord	35.44	35.54	36.54	36.64	39.31	39.63	46.44	50.00
Ground water level	6.02	6.02	6.02	6.02	6.02	6.02	6.02	6.02

Grid line	17	18	19	20	21	22	23	24
X-Coord	59.46	61.83	63.06	63.08	69.03	73.57	75.33	82.47
Ground water level	6.02	6.02	6.02	6.02	6.02	6.02	6.02	6.02

Grid line	25
X-Coord	135.00
Ground water level	6.02

Piezometric surfaces associated with individual strata

Grid line	1	2	3	4	5	6	7	8
X-Coord	0.00	9.14	20.88	23.19	29.82	32.41	33.64	34.53
Surface	Piezometric elevation							
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00

Grid line	9	10	11	12	13	14	15	16
X-Coord	35.44	35.54	36.54	36.64	39.31	39.63	46.44	50.00
Surface	Piezometric elevation							
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00

Grid line	17	18	19	20	21	22	23	24
X-Coord	59.46	61.83	63.06	63.08	69.03	73.57	75.33	82.47
Surface	Piezometric elevation							
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00

Grid line	25
X-Coord	135.00
Surface	Piezometric elevation
2	0.00
3	7.00

NON-CIRCULAR SLIP SURFACE DATA

Point no.	X Coord	Y Coord
1	19.00	6.50
2	80.00	3.00
3	100.00	24.16

ANALYSIS OPTIONS

Method of analysis: JANBU - Horizontal interslice forces
Factors of safety calculated on Soil Strength
Partial factor of safety on tan(phi) = 1.000
Partial factor of safety on drained cohesion = 1.000
Partial factor of safety on undrained cohesion = 1.000
Partial factor of safety on soil weight = 1.000
Partial factor of safety on surcharge loads = 1.000
Minimum number of slices = 10

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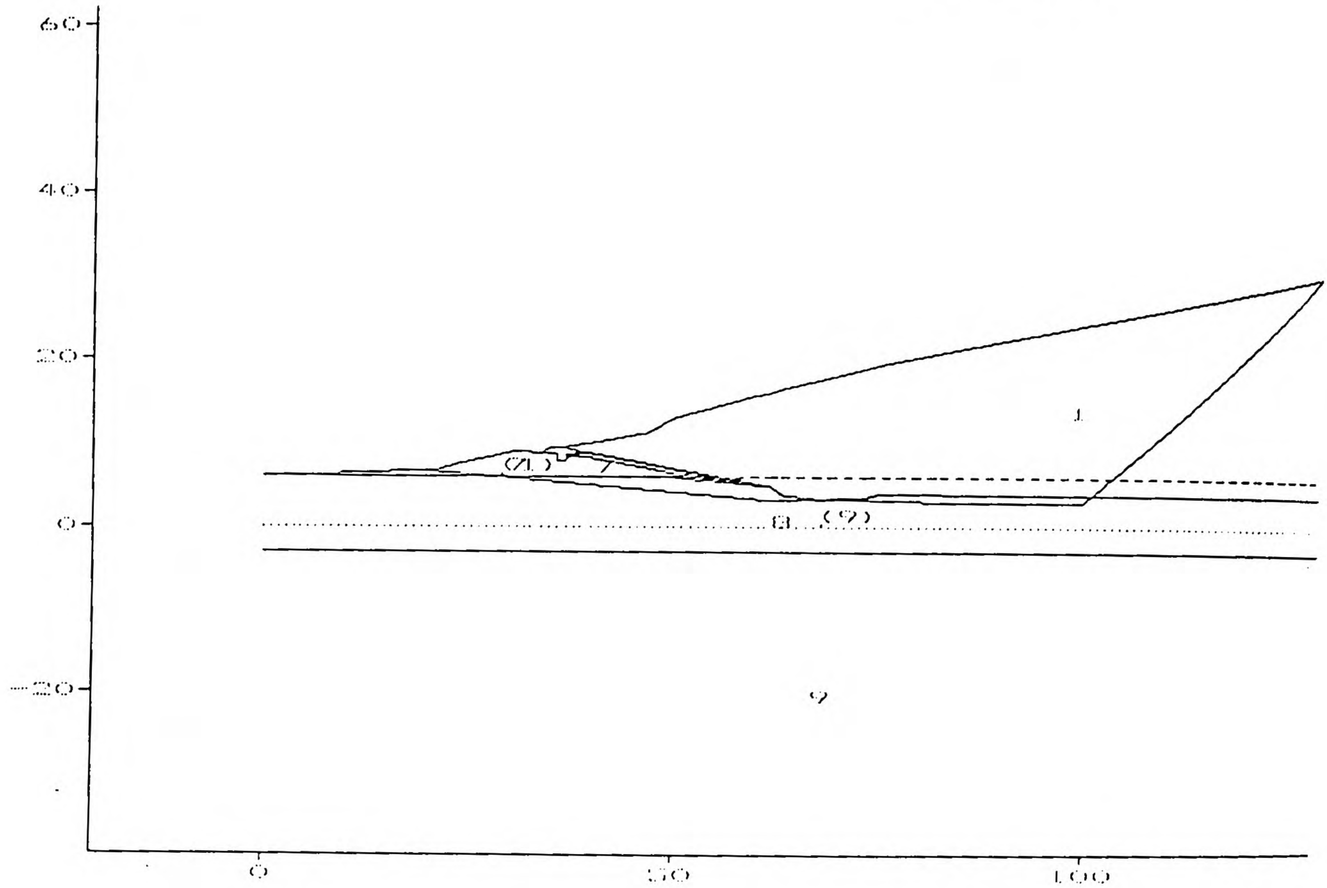
[redacted] Eastern Extension
Section F east slope non circular upper range

Sheet No.	
Run No.	FNC1
Job No.	026
Made by :	DJG
Date:	4-03-1999
Checked :	

Units: KN,M



Scale = 1 : 913

Factor of safety = 1.813

KENNEDY AND DONKIN LTD

Program: SLOPE Version 9R.01 Revision A01.B01.R19
Licensed from GEOSOLVE

[redacted] Eastern Extension
Section F east slope non circular upper range

Sheet No.	
Run No.	FNC1
Job No.	026
Made by :	DJG
Date:	4-03-1999
Checked :	

Units: KN,M

INPUT DATA

PROFILE DATA

Grid line	1	2	3	4	5	6	7	8
X-Coord	0.00	9.14	20.88	23.19	29.82	32.41	33.64	34.53
Stratum	Y-Coordinates							
1(GL)	6.02	6.10	6.58	7.28	8.63	8.89	8.84	9.38
2	6.02	6.10	6.58	7.28	8.63	8.89	8.84	9.38
3	6.02	6.10	6.58	7.28	8.63	8.89	8.84	9.38
4	6.02	6.10	6.58	7.28	8.63	8.89	8.84	8.84
5	6.02	6.10	6.58	7.28	8.63	8.89	8.84	8.84
6	6.02	6.10	6.58	7.28	8.63	8.89	8.84	8.84
7	6.02	6.10	6.58	7.28	8.63	8.89	8.84	8.84
8	6.02	6.02	6.02	6.02	6.02	6.02	6.02	6.02
9	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00

Grid line	9	10	11	12	13	14	15	16
X-Coord	35.44	35.54	36.54	36.64	39.31	39.63	46.44	50.00
Stratum	Y-Coordinates							
1(GL)	9.36	9.36	9.35	9.35	9.80	9.85	11.00	13.00
2	9.36	9.36	9.35	9.35	9.09	9.06	7.76	7.13
3	9.36	9.36	9.35	9.35	8.86	8.86	7.56	6.93
4	8.84	7.83	7.83	8.78	8.85	8.85	7.55	6.92
5	8.84	7.82	7.82	8.73	8.84	8.84	7.54	6.91
6	8.84	7.82	7.82	8.68	8.39	8.33	7.03	6.48
7	8.84	7.81	7.81	8.62	8.38	8.33	7.03	6.47
8	6.02	6.02	6.02	6.02	6.02	6.02	6.02	6.02
9	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00

Grid line	17	18	19	20	21	22	23	24
X-Coord	59.46	61.83	63.06	63.08	69.03	73.57	75.33	82.47
Stratum	Y-Coordinates							
1(GL)	15.41	16.01	16.32	16.33	17.84	19.00	19.34	20.74
2	5.47	5.14	4.17	4.17	3.48	3.64	4.00	4.00
3	5.27	4.88	3.97	3.97	3.28	3.44	3.80	3.80
4	5.26	4.87	3.96	3.96	3.28	3.44	3.79	3.79
5	5.25	4.87	3.96	3.96	3.28	3.44	3.79	3.79
6	5.00	4.87	3.96	3.96	3.28	3.44	3.79	3.79
7	4.99	4.86	3.95	3.96	3.28	3.44	3.79	3.79
8	4.99	4.86	3.95	3.96	3.28	3.44	3.79	3.79
9	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00

PROFILE DATA (continued)

Grid line 25
X-Coord 135.00

Stratum	Y-Coordinates
1(GL)	31.00
2	3.98
3	3.78
4	3.77
5	3.77
6	3.77
7	3.77
8	3.77
9	-3.00

SOIL PROPERTIES

--- Stratum --- No.	Description	Bulk unit wt. below GWL KN/M3	Bulk unit wt. above GWL KN/M3	Strength parameters C KN/M2	Phi (deg)	dC/dY KN/M2/M	Datum for C
1	WASTE	11.00	11.00	0.00	27.00	Piezometric surface 1	
2	DRAINAGE STONE	20.00	18.00	0.00	33.00		
3	CLAY COVER	18.00	18.00	25.00	0.00		
4	HDPE/ABTEX	10.00	10.00	0.00	8.00		
5	COMPACTED CLAY	18.00	18.00	25.00	0.00		
6	GEOGRID	10.00	10.00	0.00	30.00		
7	CLAY BUND	18.00	18.00	10.00	0.00		
8	ALLUVIUM	18.00	18.00	6.00	0.00	13.00	6.02
9	GRAVEL	20.00	20.00	0.00	45.00	Piezometric surface 2	

GROUND WATER CONDITIONS

Unit wt. of water = 9.81 KN/M3

Grid line	1	2	3	4	5	6	7	8
X-Coord	0.00	9.14	20.88	23.19	29.82	32.41	33.64	34.53
Ground water level	6.02	6.02	6.02	6.02	6.02	6.02	6.02	6.02

Grid line	9	10	11	12	13	14	15	16
X-Coord	35.44	35.54	36.54	36.64	39.31	39.63	46.44	50.00
Ground water level	6.02	6.02	6.02	6.02	6.02	6.02	6.02	6.02

Grid line	17	18	19	20	21	22	23	24
X-Coord	59.46	61.83	63.06	63.08	69.03	73.57	75.33	82.47
Ground water level	6.02	6.02	6.02	6.02	6.02	6.02	6.02	6.02

Grid line	25
X-Coord	135.00
Ground water level	6.02

Piezometric surfaces associated with individual strata

Grid line	1	2	3	4	5	6	7	8
X-Coord	0.00	9.14	20.88	23.19	29.82	32.41	33.64	34.53
Surface	Piezometric elevation							
1	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Grid line	9	10	11	12	13	14	15	16
X-Coord	35.44	35.54	36.54	36.64	39.31	39.63	46.44	50.00
Surface	Piezometric elevation							
1	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Grid line	17	18	19	20	21	22	23	24
X-Coord	59.46	61.83	63.06	63.08	69.03	73.57	75.33	82.47
Surface	Piezometric elevation							
1	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Grid line	25
X-Coord	135.00
Surface	Piezometric elevation
1	6.00
2	0.00

NON-CIRCULAR SLIP SURFACE DATA

Point no.	X Coord	Y Coord
1	20.88	6.58
2	60.00	3.50
3	100.00	3.00
4	134.00	30.80

ANALYSIS OPTIONS

Method of analysis: JANBU - Horizontal interslice forces
Factors of safety calculated on Soil Strength
Partial factor of safety on tan(phi) = 1.000
Partial factor of safety on drained cohesion = 1.000
Partial factor of safety on undrained cohesion = 1.000
Partial factor of safety on soil weight = 1.000
Partial factor of safety on surcharge loads = 1.000
Minimum number of slices = 10

APPENDIX 4

Example of Probabilistic Risk Assessment for a Containment Landfill

**** CBC

**** ENCAPSULATION CELL: ASSESSMENT OF RISK TO GROUNDWATER

SUMMARY REPORT

DECEMBER 1999

Prepared by:
PB Kennedy & Donkin Ltd
29 Cathedral Road
Cardiff
CF1 9HA

Report Title	**:**	****** Encapsulation Cell: Assessment of Risk to Groundwater**
Report Issue:		**2**
Job No.	**:**	**BECCF***/*****
Date	**:**	**December 1999**
Prepared by	**:**	**...** **A.C.D. Groves**
Checked by	**:**	**...** **K.C. Davies**
Check Cat	**:**	**C**
Approved by	**:**	**...** **A. Dolecki**

****** ENCAPSULATION CELL**
ASSESSMENT OF RISK TO GROUNDWATER

CONTENTS

1.0 INTRODUCTION

1.1 This report has been prepared by PB Kennedy & Donkin Limited (PBKD) on behalf of the Planning and the Highways, Transportation and Engineering Departments of **** CBC as part of the proposed extension to the encapsulation cell at ****, ****. The extension will increase the capacity of the cell from 60,000m^3 to about 270,000 m^3.

1.2 The report presents a technical summary of the results of a risk assessment of the potential effects of the leakage of leachate from the cell on the groundwater environment. It has been prepared for use by technical officers of the Environment Agency, Wales (EA), in order to satisfy Regulation 15 of the Waste Management Licensing Regulations 1994.

1.3 A risk assessment for the proposed extension was originally carried out in early 1995, which is described in the report by **** (now PBKD), "Leachate Leakage Assessment, **** Encapsulation Cell", February 1995 (No. EGMCF***/***). The initial assessment made a number of conservative assumptions as it was limited by the site specific information available. The main conclusion, however, was that the possible leakage did not represent a significant risk to human health or the environment.

1.4 The following report describes the revisions which have been made to the original work, principally the following:

- Incorporation of monitoring information obtained at the site since filling of the cell took place, mainly regarding site groundwater levels and 'leachate' quality.
- An increase in the design permeability of the bentonite-enriched sand (BES) mineral liners from 10^{-10}m/sec to 10^{-9}m/sec; the value specified in the Waste Management Licence.
- Use of Monte Carlo techniques to obtain a probabilistic output of leakage rates and leachate chemistry, as required by the EA. The computer programme used for this was LANDSIM (version 1.08).

1.5 Full descriptions of the site location, construction etc are not included as these have been provided in the previous report, to which reference should be made. The main conclusion is that the revisions undertaken verify the conclusions made within the original assessment.

1.6 The official Council Order for this work is No.******, dated ******.

2.0 DESCRIPTION

2.1 Location

2.1.1 The site location is shown on Figure 3 within the original assessment report of 1995, which also shows the main water features identified. A copy of Figure 3 is included within this review.

2.2 Groundwater Monitoring and Hydrogeology

2.2.1 A total of 18 groundwater monitoring boreholes were drilled by rotary open-hole (air flush) methods outside the perimeter of the original cell in June 1994. A number of these subsequently became blocked or destroyed and were replaced in 1995. The borehole locations are shown on Figure 1, whilst the construction details are summarised in Table 1.

2.2.2 Immediately prior to and during the initial phase of filling in late 1994 and 1995, the boreholes were dipped on a regular basis (approximately fortnightly but more regularly on occasions), during groundwater sampling, which was undertaken on behalf of **** CC by **** (***). Since 1997 the monitoring has proceeded on an approximate quarterly basis. The groundwater level information obtained during the period of greatest monitoring frequency, between February 1994 and July 1996, is summarised in Table 1.

2.2.3 Within the original assessment it was surmised that the likely groundwater flow direction was eastwards on account of the steep topographic gradient towards the **** River. At that stage, however, the possibility of a south-easterly flow direction, towards a private groundwater abstraction (shown as 'F' on Figure 3) could not be ruled out on account of the absence of local data. Review of the data summarised in Table 1 confirms that the general direction of groundwater movement is across the site to the north and north-east, with a more easterly component of flow over the north-eastern corner of the cell.

2.2.4 The mean groundwater levels across the site between February 1994 and July 1996, within Table 1 are shown as contours on Figure 1. The following observations are made:

- Comparison of Figure 1 with the base elevations of the cell show that an unsaturated zone is present beneath the whole of the site.
- Groundwater levels are significantly lower on the north-eastern and eastern margin of the cell, in the vicinity of boreholes BH6-9. This is attributed to a facies change to the east of the eastern cell margin, where coarse glacial drift are encountered. The original hydrogeology report shows a suspected glacial washout above the Brithdir seam in this area (see **** report no. *******, April 1993, Figure *).
- An easterly component of flow is consistent with field observations of seepage from the base of the restored eastern faces, shown on Figure 1.

- The water levels recorded in borehole BH1, to the north-west of the cell are much higher than recorded in the adjacent boreholes. This borehole is located close to the boundary stream and the water levels are attributed to leakage of surface water through a poorly finished borehole installation. (The water chemistry results for this borehole are also anomalous, as discussed below).

2.3 Groundwater Quality

2.3.1 The groundwater samples obtained by *** were analysed for a range of general determinands, and show the groundwaters in proximity to the cell to be typical of what would be expected for an area within the Coal Measures. The reported results are typically slightly acidic (pH 5-6.5) and low in mineralisation, with elevated dissolved iron. Concentrations of cyanide, phenols and BTEX are below laboratory detection limits.

2.3.2 The groundwater chemistry from borehole BH1 is noticeably different, being alkaline (pH8-11), with higher mineralisation and persistently detectable concentrations of cyanide, the latter reported as "free cyanide" by ***, up to 0.108mg/l. The latter may be a reporting error, however the presence of cyanide at this location clearly points to an anthropogenic input to the groundwater, and may be due to contaminated run-off.

2.4 Rainfall and Discharge Monitoring

2.4.1 A rain gauge has been operated at the site since March 1994 and indicates a mean annual rainfall of approximately 2045mm.

2.4.2 The current surface landform is shown on Figure 1. Details of the lining system for the encapsulation cell are shown in Figure 4. The basal system is a double liner comprising a HDPE/BES composite upper liner and a BES mineral lower liner, separated by a leachate detection layer.

2.4.3 At present, when it rains, runoff enters the leachate drainage layer, above the HDPE/BES composite, where it is uncovered at the surface. If left unattended, the drainage layer becomes full on the northern side of the cell and overtops in to the adjacent stream. The drainage layer is therefore pumped in to the holding lagoon within approximately 24 hours of a storm event occurring. Detailed measurements of the volumes of water pumped in to the lagoon between late 1997 and early 1998 indicated that between 11-12.5% of incident rainfall on to the cell infiltrated the leachate drainage layer.

2.5 Leachate Chemistry

2.5.1 When the holding lagoon is full, it is tested and, if compliant with the existing discharge consent for the site, it is discharged in to the adjacent stream, which is lined with stone pitching downstream to the point shown on Figure 1. A summary of the testing results obtained between December 1995 and July 1999 is shown in Table 2.

2.5.2 Consideration of the details given in Section 2.4 above, indicates that the data from the holding tank may not reflect that of true "leachate" within the cell, i.e. that which is percolating through the waste mass. The rapid infiltration of runoff may be expected to dilute such seepage and cause a flushing action within the drainage layer. Following consultation with the EA in August 1999, arrangements were made to sample directly from the leachate drainage layer. During a period of dry weather in early September 1999, this layer pumped dry and the sump allowed to recharge for a period of three days, following which it was sampled. The results of this analysis, together with those of the only other sample taken directly from the leachate riser through the life of the site are shown on the right hand side of Table 2.

2.5.3 The results show that when not being flushed by the rainfall 'run-in', the chemistry of the water within the leachate drainage layer deteriorates slightly, as would be expected. This is seen as a reduction in pH and increases in ammoniacal nitrogen, sulphate and total cyanide, together with the metals copper and zinc.

2.5.4 It is considered, however, that whilst useful as a guide, the information cannot be guaranteed to represent the actual chemistry of percolating porewaters in a restored and capped landform.

3.0 SUMMARY OF RISK ASSESSMENT METHODOLOGY

3.1 Initial Assessment

3.1.1 The construction details for the base of the encapsulation cell and basal liner are shown on Figures 3 & 4 respectively.

3.1.2 The initial assessment simplified the calculation of potential leakage by only considering leakage through the upper HDPE/BES composite. It used a permeability of 10^{-10}m/sec for the BES and concluded, using the method of Giroud and Bonarparte (1989), that leakage would be considerably less than 43l/day, and would probably be less than 5l/day.

3.1.3 The input parameters on leachate quality were made using assumptions on the types of material likely to be present in the wastes from a coking plant, including polyaromatic hydrocarbons (PAHs), such as naphthalene and benzo(a)pyrene, phenols and volatile organic compounds (VOCs), typified by benzene. The assessment made a number of conservative assumptions regarding the partition of these compounds and attenuation in the environment and concluded that there was no significant risk to humans or the environment.

3.2 Simulation Undertaken

3.2.1 The present assessment has been based around the use of the LANDSIM computer programme (v 1.08), which simulates the performance of a landfill and produces a probabilistic output leakage rate and chemistry using the Monte Carlo Method.

3.2.2 It should be recognised that the most up to date version of the model cannot simulate a composite/double barrier system of the type used in the encapsulation cell at **** directly. For this reason the barrier system has been simulated in two LANDSIM models; <****1.SIM> representing the upper HDPE/BES composite, and <****2.SIM> representing the lower BES, below the leachate detection layer. The methodology used is described on the print-outs of the two runs, which are included as Appendix 1.

3.2.3 In summary, the main points of the hydraulics of the simulations undertaken are as follows:

- Both models use a permeability of 10^{-9}m/sec for the BES, in accordance with the Site Licence.
- In all other respects the landfill geometry is as described in the initial study.
- Both models assume that the site operates in accordance with the Site Licence, i.e. that the allowable heads of 1m in the leachate drainage layer (above the upper HDPE/BES composite) and 1m in the leachate detection layer (above the BES) are maintained.

- In both models the depth and attenuation capacities of the 'unsaturated zone' are limited to assess the chemistry of the leaking material immediately below the respective liner.
- Model <****1.SIM> assumes that infiltration into the landfill is 100mm/year (it will be considerably less than this and may be negligible, however sensitivity analysis with 10mm/year indicates no appreciable difference in the steady-rate leakage rates generated by the model, which are controlled by the fixed head above the liner).
- This indicates that the leakage rate through the upper liner in to the leakage detection layer is likely to be greater than 6.9l/day and less than 402 l/day, based on the 5%ile and 95%ile steady-state flows respectively. It should be noted that the leakage distribution is highly negatively skewed.
- In agreement with the EA, model <****2.SIM> takes the 95%ile leakage from <****1.SIM> as "infiltration", which is equivalent to about 16.3mm/year over the area of the cell base. Note: no standard deviation has been allocated to this infiltration, on account of the very slow movement, which, though considered reasonable is not strictly in accord with the model assumptions. The standard deviation is the governing factor on the output distribution.
- This model suggests that all the infiltration entering the layer will ultimately leak through the base (402/sec), because of the 1m fixed head criterion imposed, which is the maximum allowable head within the Site License.

3.2.4 The last point is obviously a "worst case" as the model assumes that in the long-term a 1m head is present over the whole base of the cell. Calculations included as Appendix 2 suggest that only a small fraction of this figure (about 12 l/day) would leak through the lower BES liner, assuming the leachate detection layer worked efficiently and the site was operated in accordance with the Site Licence.

3.3 Leachate Chemistry

3.3.1 The greatest uncertainty regarding the assessment arises from prediction of the long-term quality of water as it percolates through the waste mass. The chemistry summarised in Table 2 indicates that ammoniacal nitrogen and total cyanide appear to be the most sensitive parameters within the existing leachate, cyanide being the only List I substance detected. Simulations were therefore made with these determinands, together with the following:

- Phenols (see paragraph 3.1.3 above), to date undetected above laboratory detection limits of 20μg/l.
- Copper, as an example of a highly soluble metal.

3.3.2 BTEX were not simulated as they have not been detected above laboratory detection limits and because within in a reducing environment with available electron acceptors (e.g. sulphate), these compounds might be expected readily to degrade.

3.3.3 Because of the uncertainties over what the *actual* concentrations of the above might be present within the leachate in the long term, the input concentrations in <****1.SIM> were set at approximately 10 times the concentrations obtained from the holding lagoon; the mean concentration corresponding to the "likely" input concentration required within the model. With these input parameters the resultant long-term chemistry of leakage in to the leachate detection layer (assuming a non-declining source term) is given as:

- Ammoniacal nitrogen concentrations likely to be less than 1.67mg/l (99% confidence), which is less than the existing discharge consent, with a significant likelihood of being less than 0.63mg/l (95% confidence);
- Copper concentrations likely to be less than 27µg/l (99% confidence), which is slightly more than the likely surface water EQS in acidic waters (1-28µg/l), with a significant likelihood of being less than 9µg/l (95%);
- Total cyanide concentrations likely to be less than 0.172mg/l (99% confidence), with a significant likelihood of being less than 59µg/l at the 95% confidence level. The latter is only slightly greater than the surface water EQS for total cyanide;
- Phenol concentrations likely to be less than 5µg/l at the 99% confidence level, with a significant likelihood of being less than 1.8µg/l at the 95% level. The latter is less than the 10µg/l total hydrocarbons allowable within Drinking Water.

3.3.4 These output values were input in to <****2.SIM>, the 'maximum', 'likely' and 'mean' contaminant concentrations being taken as 99%, 50% and 5%ile concentrations respectively derived from <****1.SIM>. The resultant 95%ile concentrations output by the model (also assuming a non-declining source term) suggest contaminant concentrations approaching current laboratory detection limits and likely environmental background, as follows:

- Ammoniacal nitrogen – 0.026mg/l.
- Copper - 0.32µg/l.
- Total cyanide – 2.25µg/l.
- Phenols – 0.06µg/l.

3.35 As a sensitivity analysis the model was also run with a 'declining' source term, which attempts to simulate the reduction in contaminant available for leaching through time. In this mode the peak concentrations occur at a finite time after the onset of leaching, as expected, and are slightly lower (but not significantly so) than those with the non-declining source term. This is discussed below, with particular reference to cyanide.

3.4 Comment on Cyanide Degradation

3.4.1 As a List I substance cyanide must be prevented from entering groundwater, although in practice it is free cyanide, which is more toxic to the environment. The LANDSIM model predicts that a finite amount of total cyanide would enter the groundwater beneath the site at some point in the future. The 95%ile concentration predicted by the model is below current laboratory detection limits, however this is still considered to be unrealistic and is attributed to over-simplification within the model.

3.4.2 Under reducing conditions, particularly if sulphide is available, it is extremely likely that the cyanide would complex and precipitate from solution. Published data indicate that total cyanide follows a theoretical first order decay curve and is not released (i.e. in to solution) at concentrations below 0.1mg/l (see "Cyanide Chemistry and Treatment of Cyanide Waste", Smith and Mudder). This is not taken into consideration in the model results, summarised above. In addition, the simulation has incorporated what is very likely to be a conservatively high input concentration and ignored the attenuation properties of the unsaturated zone beneath the lower BES liner. These factors are likely to reduce the theoretical output concentrations significantly from those shown in Appendix 1. It is concluded that the potential risk to the environment from leaching of cyanide is therefore negligible.

4.0 CONCLUSIONS

4.1 The risk assessment undertaken suggests that the steady-state leakage into the leachate detection layer is likely to be below 402 l/day. This is greater than the flows originally anticipated in 1995. The main reason for this is the larger permeability of 10^{-9}m/sec used in the model, taken from the Site Licence.

4.2 Monitoring data collected at the site in the period since the original assessment was undertaken has confirmed that the movement of groundwater beneath the cell is to the north-east and east. There is no evidence of a south-easterly movement of groundwater and the abstraction at *** *** Farm is therefore not considered at risk.

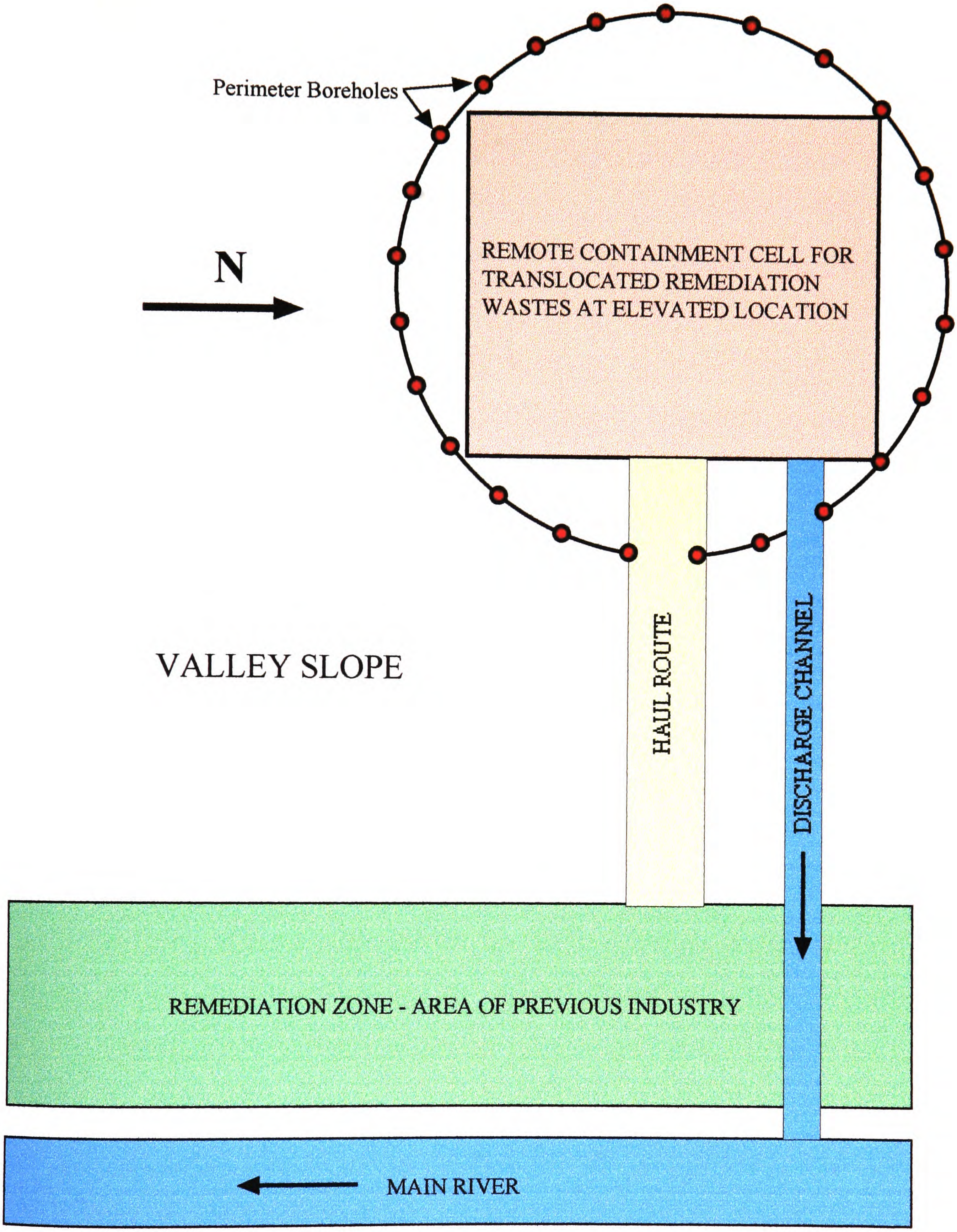
4.3 Monitoring of site leachates has indicated that the most sensitive potential contaminants to groundwater from within the cell are total cyanide and ammoniacal nitrogen. The long-term quality of the leachates is likely to be of poorer quality to that monitored to date on site.

4.4 The model has therefore incorporated a factor of safety of 10 times within the concentrations of contaminants detected in the site leachates. The results from these simulations indicate that by the time leakage leaves the lower mineral liner of the encapsulation cell the contaminant concentrations are likely to be so low as to provide no material risk to the groundwater environment beneath the site.

4.5 Notwithstanding the above, it is recommended that following completion of the infilling and capping of the site extension, that monitoring of the water quality within the leachate drainage layer is undertaken in order to verify the assumptions made within this assessment. This is considered to be consistent with the "requisite surveillance" required under Regulation 15(3) of the Waste Management Licensing Regulations 1994.

4.6 The scope of the analytical analysis to be undertaken should be clarified with the Environment Agency.

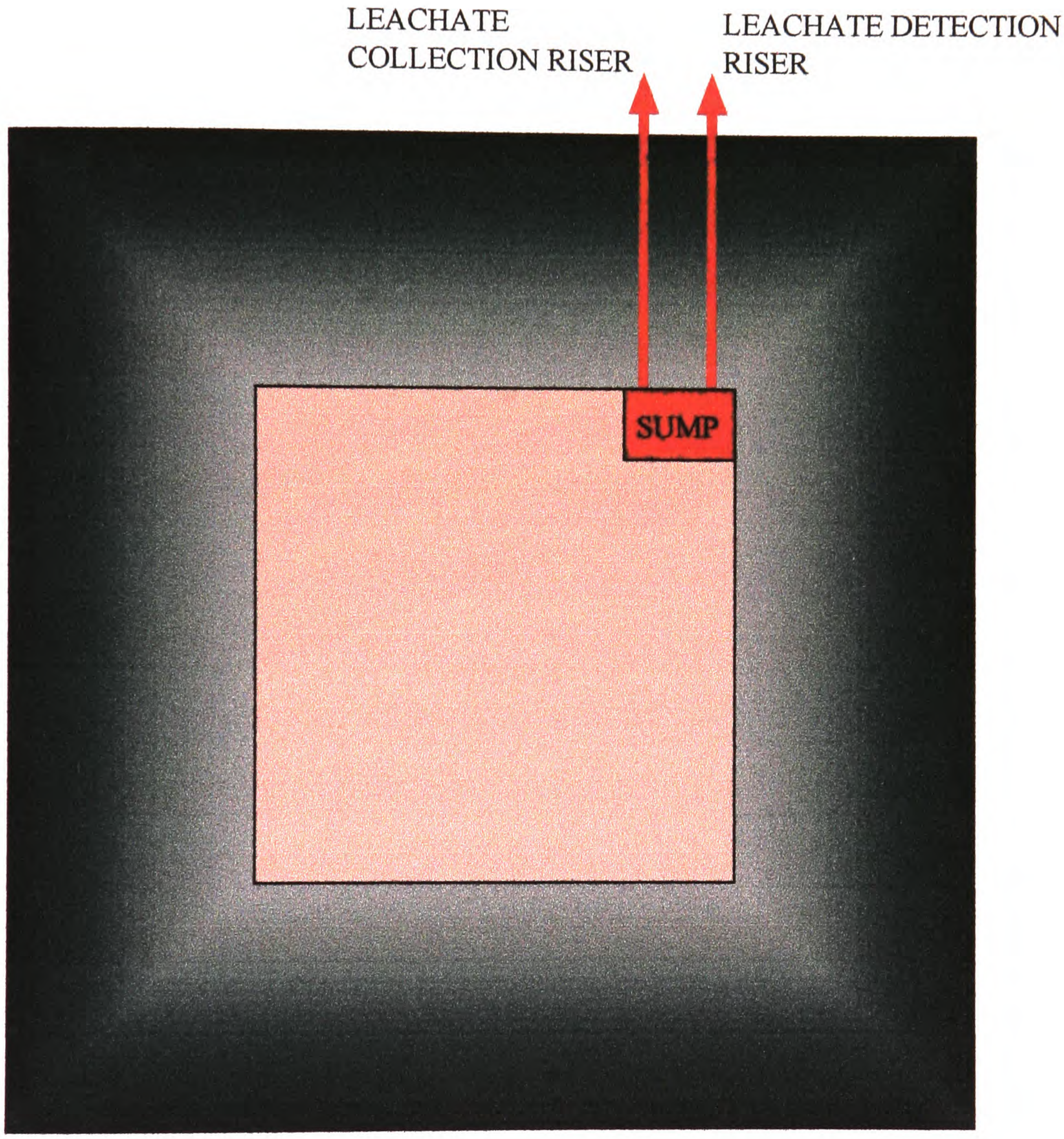
FIGURES



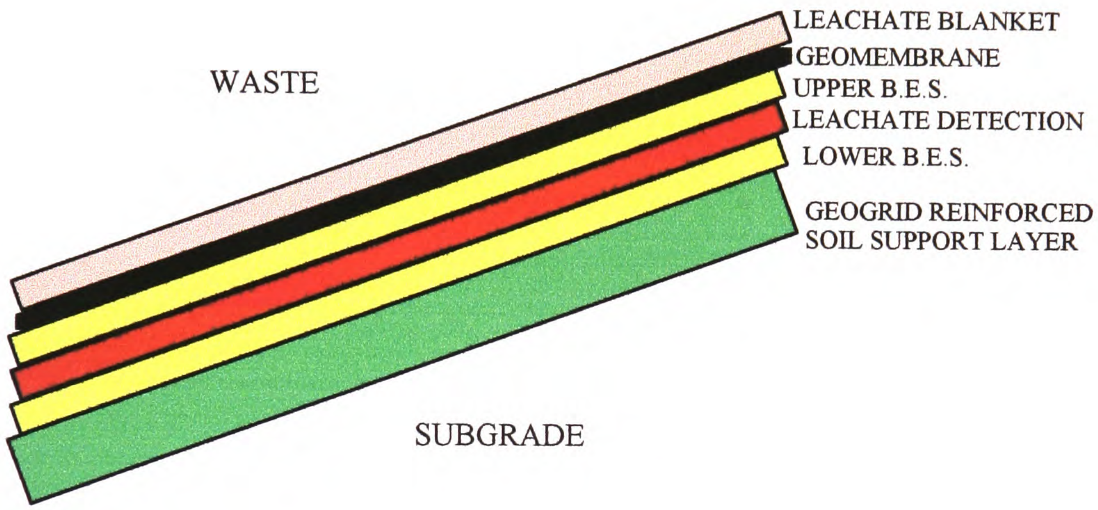
APPENDIX4 - FIGURE 1: DIAGRAMMATIC REPRESENTATION OF CONTAINMENT CELL AND REMEDIATION ZONES ADJACENT TO MAIN RIVER

DETAILS LEFT BLANK

APPENDIX4 - FIGURE 2: ABSTRACTION DETAILS
(BLANK FOR CONFIDENTIALITY)



APPENDIX4 - FIGURE 3: CELL, SUMP AND RISER LAYOUT



APPENDIX 4 - FIGURE 4: CELL LINER DETAILS

TABLES

Borehole No.	Cover Level (m AOD)	Depth Drilled (mbgl)	Open Section (mbgl)	GROUNDWATER ELEVATIONS (mAOD) 2/94-7/96			
				No. Readings	Max	Min	Mean
1	236.817	19.35	2.80-19.35	33	234.587	228.017	232.26
2	233.265	20	2.70-20	34	221.77	210.765	212.26
3	227.818	19.4	2.70-19.40	36	224.658	219.32	221.67
4	224.194	18.1	2.70-18.10	36	222.484	219.58	220.89
5	224.874	18.3	2.70-18.30	34	232.98	216.68	218.32
6	225.33	15.9	2.70-15.90	35	216.16	214.43	214.98
7	228.912	14.1	2.50-14.10	36	218.572	210.63	213.83
8	233.275	14.15	2.50-14.15	35	220.655	207.92	214.24
9	236.219	25.3	2.70-25.30	33	225.69	211.35	213.62
10	235.563	29.1	2.70-29.10	36	233.613	223.14	226.09
11	233.745	29.2	2.50-29.20	36	230.585	208.95	225.86
12a	241.209	31.5	2.60-27.30	36	229.739	222.38	228.04
13b	246.64	31.5	2.80-29.70	34	235.88	227.32	228.88
14	250.528	30.25	2.50-30.25	36	242.09	226.53	228.97
15	251.816	29.6	2.50-29.60	30	235.13	227.91	229.14
16a	244.174	28.4	2.50-28.40	36	232.784	223.01	228.4
17a	239.569	34	2.50-22	35	229.549	226.8	228.29
18	236.373	23.7	2.50-23.70	36	233.62	225.54	230.03

Table 1: [redacted] Encapsulation Cell: Summary of Groundwater Monitoring Information.

Determinands	Leachate Holding Tank 12/95 - 7/99				Leachate Riser	
	No.Dets	Max	Min	Mean	21/5/98	09/08/99
pH	16	8.3	6.9	7.86	5.4	6
COD	15	28	<12	15.67	51	28
Ammonia as N	15	1.9	<0.5	1.002	2.7	1.5
Total N oxidised as N	15	4.9	0.6	2.712	1.8	5.5
Total SS	15	35	<1.5	7.667	65	
Free Cyanide	16	0.02	<0.001	0.007	0.01	0.002
Total Cyanide	15	0.096	0.004	0.033	0.51	0.126
Copper Total	15	0.015	0.003	0.008	0.0668	0.0273
Zinc Total	15	0.095	0.019	0.067	0.742	0.343
Lead Total	15	<0.0002	<0.0002		<0.002	<0.002
Chromium Total	15	0.002	0.00063	0.001	<0.0005	0.00213
Nickel Total	15	0.143	0.035	0.062	0.268	0.142
Oil and Grease	14	2.1	<0.01			<0.3
Phenols Monohyydric	16	<0.02	<0.02		<0.02	<0.02
Sulphate Total	16	1226	32	692	1810	1290
Conductivity	1			1509		
Iron Diss	1			6.89		
Iron Total	1			16.4		
Toluene	1			<0.1		<0.1
Benzene	1			<0.1		<0.1
M-Xylene	1			<0.1		
O-Xylene	1			<0.1		<0.1
P-Xylene	1			<0.1		
Total Sulphide	9	<0.005	<0.009		0.009	

Table 2: [redacted] Encapsulation Cell: Summary of Available Leachate Chemistry

APPENDICES

Infiltration Information

Water entering landfill through top (mm/year): normal distribution.

Mean:	100
Standard deviation:	60

Justification for Specified Infiltration
No difference in leakage rates for 10mm/yr or 100mm/yr infiltration due to fixed head criterion. 60mm standard deviation because of normal rainfall distribution through out year.

Barrier Information

Justification for Engineered Barrier Type
Use default from LandSim user manual

There is a composite barrier
Liner installed under CQA

Design thickness of liner:	0.3 (m)
Variability in thickness of liner:	5 (%)

Justification for Clay or BES Substrate Properties
300mm BES shown on Drawing No. 50 QA 89/5055. Hydraulic conductivity properties from licence.

Hydraulic conductivity of mineral lower liner (m/s): log. triangular distribution.

Minimum value:	1.0E-10
Most likely value:	1.0E-9
Maximum value:	1.0E-8

Membrane defects (per hectare): triangular distribution.

Pin holes:	
Minimum value:	0
Most likely value:	25
Maximum value:	25
Holes:	
Minimum value:	0
Most likely value:	5
Maximum value:	5
Tears:	
Minimum value:	0
Most likely value:	0.1
Maximum value:	2

Justification for Flexible Membrane Liner
Use default from LandSim user manual

Drainage Information

Type of drainage:	blanket
Degenerate settings.	
Head on EBS is given as:	1 (m)

Justification for Specified Head
Maximum leachate head of 1m allowed by site licence.

Calculation Settings

Number of iterations:	3000
Calculated values used as input	
Unretarded values used for simulation	
Timeslices at:	30, 100, 300, 1000 (years)

Cell dimensions

Cell width:	94 (m)
Cell length:	96 (m)
Cell top area:	23500 (m^2)
Cell base area:	9024 (m^2)
Number of cells:	1

Justification for Landfill Geometry
Dimensions and layout from Drawing No. 50 QA 89/5054. Sump diameter calculated from equation 3.1 (landsim release 1 manual) input diameter = SQRT (4*sump area/ 3 14159)

Unsaturated pathway parameters

Modelled as unsaturated pathway
Pathway length (m): uniform distribution.

Minimum length:	0
Maximum length:	1
Flow Model:	porous medium

Pathway moisture content (%): uniform distribution

Minimum moisture content:	1
Maximum moisture content:	30

Justification for Geometry
Unjustified change made to LandSim default

Pathway porosity (m/s): uniform distribution.

Minimum porosity:	1
Maximum porosity:	1

Pathway hydraulic conductivity values (m/s): log. triangular distribution.

Minimum:	1.0E-10
Likely:	1.0E-7
Maximum:	1.0E-4

Justification for Hydraulics Properties
Parameters selected to minimise path length and therefore assess groundwater chemistry immediately outside barrier. [CHANGED] [CHANGED]

Pathway longitudinal dispersivity (m): log. uniform distribution.

Minimum dispersivity	0.0000000001
Maximum dispersivity	1

Pathway transverse dispersivity (m): log. uniform distribution.

Minimum dispersivity:	0
Maximum dispersivity:	0.1

Justification for Dispersion Properties
Use default from LandSim user manual

Cation exchange capacity (meq/kg): triangular distribution.

Minimum CEC:	0.0
Likely CEC:	0.1
Maximum CEC:	0.2

Justification for CEC Sorption Parameters
Use default from LandSim user manual

Minimum reaction efficiency:	0.25
Likely reaction efficiency:	0.35
Maximum reaction efficiency:	0.4

Justification for Reaction Efficiency
Use default from LandSim user manual

Vertical pathway parameters

Modelled as vertical pathway
Pathway length (m): uniform distribution.

Minimum length:	0
Maximum length:	10

Pathway porosity (m/s): uniform distribution.

Minimum porosity:	0.1
Maximum porosity:	0.5

Justification for Geometry
Use default from LandSim user manual

Pathway hydraulic conductivity values (m/s): log. triangular distribution.

Minimum:	1.0E-9
Likely:	1.0E-7
Maximum:	1.0E-5

Justification for Hydraulics Properties
Use default from LandSim user manual

Pathway dispersivity (m): log. uniform distribution.

Minimum dispersivity	0.0000000001
Maximum dispersivity	1

Pathway transverse dispersivity (m): log. uniform distribution.

Minimum dispersivity:	0
Maximum dispersivity:	0.1

Justification for Dispersion Details
Use default from LandSim user manual

Aquifer pathway parameters

Modelled as aquifer pathway.
Pathway length (m): uniform distribution.

Minimum length:	100
Maximum length:	1000

Pathway width (m): uniform distribution.

Minimum width:	50
Maximum width:	200

Mixing zone (m): uniform distribution.

Minimum depth:	1
Maximum depth:	10

Pathway porosity (m/s): uniform distribution.

Minimum porosity:	0.1
Maximum porosity:	0.5

Justification for Geometry
Use default from LandSim user manual

Pathway regional gradient: triangular distribution.

Minimum gradient:	0.01
Likely gradient:	0.05
Maximum gradient:	0.05

Pathway hydraulic conductivity values (m/s): log. triangular distribution.

Minimum	1.0E-6
Likely	1.0E-5
Maximum	1.0E-4

Justification for Hydraulics Properties
Use default from LandSim user manual

Pathway longitudinal dispersivity (m): log. uniform distribution.

Minimum dispersivity:	10
Maximum dispersivity:	100

Pathway transverse dispersivity (m): log. uniform distribution.

Minimum dispersivity:	1
Maximum dispersivity:	10

Justification for Dispersion Details
Use default from LandSim user manual

Retardation parameters for Unsaturated pathway

Modelled as unsaturated pathway.

No retardation values used in this simulation.
Check 'Unretarded Contaminant Transport' setting under simulation preferences.

Retardation parameters for Vertical pathway

Modelled as vertical pathway.

No retardation values used in this simulation.
Check 'Unretarded Contaminant Transport' setting under simulation preferences.

Composite

Concentration of Amm as N in biosphere

At 30 years
- 1% of 3000 iterations were less than 1.0E-30 mg/l
- 5% of 3000 iterations were less than 1.0E-30 mg/l
- 10% of 3000 iterations were less than 1.0E-30 mg/l
- 50% of 3000 iterations were less than 1.0E-30 mg/l
- 90% of 3000 iterations were less than 6.81E-2 mg/l
- 95% of 3000 iterations were less than 1.52E-1 mg/l
- 99% of 3000 iterations were less than 5.48E-1 mg/l

At 100 years
- 1% of 3000 iterations were less than 1.0E-30 mg/l
- 5% of 3000 iterations were less than 1.0E-30 mg/l
- 10% of 3000 iterations were less than 1.0E-30 mg/l
- 50% of 3000 iterations were less than 2.17E-2 mg/l
- 90% of 3000 iterations were less than 2.52E-1 mg/l
- 95% of 3000 iterations were less than 4.39E-1 mg/l
- 99% of 3000 iterations were less than 1.32E0 mg/l

At 300 years
- 1% of 3000 iterations were less than 1.0E-30 mg/l
- 5% of 3000 iterations were less than 7.52E-4 mg/l
- 10% of 3000 iterations were less than 3.68E-3 mg/l
- 50% of 3000 iterations were less than 4.42E-2 mg/l
- 90% of 3000 iterations were less than 3.53E-1 mg/l
- 95% of 3000 iterations were less than 6.08E-1 mg/l
- 99% of 3000 iterations were less than 1.57E0 mg/l

At 1000 years
- 1% of 3000 iterations were less than 7.76E-4 mg/l
- 5% of 3000 iterations were less than 3.12E-3 mg/l
- 10% of 3000 iterations were less than 5.39E-3 mg/l
- 50% of 3000 iterations were less than 4.81E-2 mg/l
- 90% of 3000 iterations were less than 3.69E-1 mg/l
- 95% of 3000 iterations were less than 6.3E-1 mg/l
- 99% of 3000 iterations were less than 1.67E0 mg/l

At infinity
- 1% of 3000 iterations were less than 7.96E-4 mg/l
- 5% of 3000 iterations were less than 3.14E-3 mg/l
- 10% of 3000 iterations were less than 5.4E-3 mg/l
- 50% of 3000 iterations were less than 4.81E-2 mg/l
- 90% of 3000 iterations were less than 3.69E-1 mg/l
- 95% of 3000 iterations were less than 6.3E-1 mg/l
- 99% of 3000 iterations were less than 1.67E0 mg/l

Concentration of copper in biosphere

At 30 years
- 1% of 3000 iterations were less than 1.0E-30 mg/l
- 5% of 3000 iterations were less than 1.0E-30 mg/l
- 10% of 3000 iterations were less than 1.0E-30 mg/l
- 50% of 3000 iterations were less than 1.0E-30 mg/l
- 90% of 3000 iterations were less than 8.22E-4 mg/l
- 95% of 3000 iterations were less than 1.99E-3 mg/l
- 99% of 3000 iterations were less than 7.19E-3 mg/l

At 100 years
- 1% of 3000 iterations were less than 1.0E-30 mg/l
- 5% of 3000 iterations were less than 1.0E-30 mg/l
- 10% of 3000 iterations were less than 1.0E-30 mg/l
- 50% of 3000 iterations were less than 2.47E-4 mg/l
- 90% of 3000 iterations were less than 3.35E-3 mg/l
- 95% of 3000 iterations were less than 6.04E-3 mg/l
- 99% of 3000 iterations were less than 1.84E-2 mg/l

At 300 years
- 1% of 3000 iterations were less than 1.0E-30 mg/l
- 5% of 3000 iterations were less than 8.9E-6 mg/l
- 10% of 3000 iterations were less than 3.69E-5 mg/l
- 50% of 3000 iterations were less than 5.24E-4 mg/l
- 90% of 3000 iterations were less than 4.75E-3 mg/l
- 95% of 3000 iterations were less than 8.79E-3 mg/l
- 99% of 3000 iterations were less than 2.48E-2 mg/l

At 1000 years
- 1% of 3000 iterations were less than 9.2E-6 mg/l
- 5% of 3000 iterations were less than 2.96E-5 mg/l
- 10% of 3000 iterations were less than 5.7E-5 mg/l
- 50% of 3000 iterations were less than 5.73E-4 mg/l
- 90% of 3000 iterations were less than 5.0E-3 mg/l
- 95% of 3000 iterations were less than 9.14E-3 mg/l
- 99% of 3000 iterations were less than 2.68E-2 mg/l

At infinity
- 1% of 3000 iterations were less than 9.51E-6 mg/l
- 5% of 3000 iterations were less than 2.99E-5 mg/l
- 10% of 3000 iterations were less than 5.73E-5 mg/l
- 50% of 3000 iterations were less than 5.73E-4 mg/l
- 90% of 3000 iterations were less than 5.0E-3 mg/l
- 95% of 3000 iterations were less than 9.14E-3 mg/l
- 99% of 3000 iterations were less than 2.72E-2 mg/l

Composite

Concentration of Cyanide in biosphere

At 30 years
- 1% of 3000 iterations were less than 1.0E-30 mg/l
- 5% of 3000 iterations were less than 1.0E-30 mg/l
- 10% of 3000 iterations were less than 1.0E-30 mg/l
- 50% of 3000 iterations were less than 1.0E-30 mg/l
- 90% of 3000 iterations were less than 4.69E-3 mg/l
- 95% of 3000 iterations were less than 1.2E-2 mg/l
- 99% of 3000 iterations were less than 4.89E-2 mg/l

At 100 years
- 1% of 3000 iterations were less than 1.0E-30 mg/l
- 5% of 3000 iterations were less than 1.0E-30 mg/l
- 10% of 3000 iterations were less than 1.0E-30 mg/l
- 50% of 3000 iterations were less than 1.26E-3 mg/l
- 90% of 3000 iterations were less than 1.93E-2 mg/l
- 95% of 3000 iterations were less than 3.93E-2 mg/l
- 99% of 3000 iterations were less than 1.23E-1 mg/l

At 300 years
- 1% of 3000 iterations were less than 1.0E-30 mg/l
- 5% of 3000 iterations were less than 3.04E-5 mg/l
- 10% of 3000 iterations were less than 1.73E-4 mg/l
- 50% of 3000 iterations were less than 2.73E-3 mg/l
- 90% of 3000 iterations were less than 3.0E-2 mg/l
- 95% of 3000 iterations were less than 5.56E-2 mg/l
- 99% of 3000 iterations were less than 1.63E-1 mg/l

At 1000 years
- 1% of 3000 iterations were less than 3.36E-5 mg/l
- 5% of 3000 iterations were less than 1.4E-4 mg/l
- 10% of 3000 iterations were less than 2.79E-4 mg/l
- 50% of 3000 iterations were less than 2.99E-3 mg/l
- 90% of 3000 iterations were less than 3.21E-2 mg/l
- 95% of 3000 iterations were less than 5.92E-2 mg/l
- 99% of 3000 iterations were less than 1.71E-1 mg/l

At infinity
- 1% of 3000 iterations were less than 3.44E-5 mg/l
- 5% of 3000 iterations were less than 1.4E-4 mg/l
- 10% of 3000 iterations were less than 2.79E-4 mg/l
- 50% of 3000 iterations were less than 2.99E-3 mg/l
- 90% of 3000 iterations were less than 3.22E-2 mg/l
- 95% of 3000 iterations were less than 5.92E-2 mg/l
- 99% of 3000 iterations were less than 1.72E-1 mg/l

Composite

Concentration of Phenols in biosphere

At 30 years
- 1% of 3000 iterations were less than 1.0E-30 mg/l
- 5% of 3000 iterations were less than 1.0E-30 mg/l
- 10% of 3000 iterations were less than 1.0E-30 mg/l
- 50% of 3000 iterations were less than 1.0E-30 mg/l
- 90% of 3000 iterations were less than 1.39E-4 mg/l
- 95% of 3000 iterations were less than 3.09E-4 mg/l
- 99% of 3000 iterations were less than 1.39E-3 mg/l

At 100 years
- 1% of 3000 iterations were less than 1.0E-30 mg/l
- 5% of 3000 iterations were less than 1.0E-30 mg/l
- 10% of 3000 iterations were less than 1.0E-30 mg/l
- 50% of 3000 iterations were less than 3.44E-5 mg/l
- 90% of 3000 iterations were less than 5.89E-4 mg/l
- 95% of 3000 iterations were less than 1.12E-3 mg/l
- 99% of 3000 iterations were less than 3.82E-3 mg/l

At 300 years
- 1% of 3000 iterations were less than 1.0E-30 mg/l
- 5% of 3000 iterations were less than 9.19E-7 mg/l
- 10% of 3000 iterations were less than 4.96E-6 mg/l
- 50% of 3000 iterations were less than 7.98E-5 mg/l
- 90% of 3000 iterations were less than 8.52E-4 mg/l
- 95% of 3000 iterations were less than 1.71E-3 mg/l
- 99% of 3000 iterations were less than 4.91E-3 mg/l

At 1000 years
- 1% of 3000 iterations were less than 8.82E-7 mg/l
- 5% of 3000 iterations were less than 4.03E-6 mg/l
- 10% of 3000 iterations were less than 7.87E-6 mg/l
- 50% of 3000 iterations were less than 8.64E-5 mg/l
- 90% of 3000 iterations were less than 9.03E-4 mg/l
- 95% of 3000 iterations were less than 1.79E-3 mg/l
- 99% of 3000 iterations were less than 5.15E-3 mg/l

At infinity
- 1% of 3000 iterations were less than 9.05E-7 mg/l
- 5% of 3000 iterations were less than 4.06E-6 mg/l
- 10% of 3000 iterations were less than 7.9E-6 mg/l
- 50% of 3000 iterations were less than 8.66E-5 mg/l
- 90% of 3000 iterations were less than 9.03E-4 mg/l
- 95% of 3000 iterations were less than 1.79E-3 mg/l
- 99% of 3000 iterations were less than 5.29E-3 mg/l

LandSim: Release 1.08

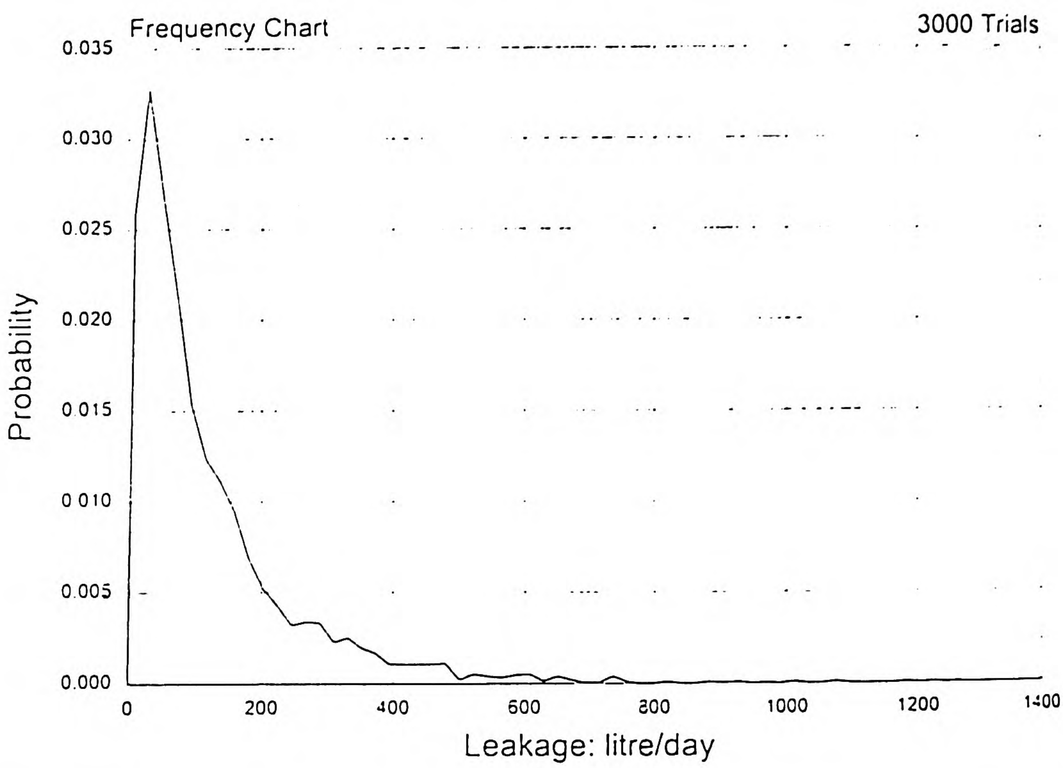
Project Name : [redacted] Encapsulation Cell - First Barrier

Project Number : BEECF048

Client : [redacted] CBC

C:\LANDSIM\[redacted]1.SIM 09/12/99 19:02:26

Forecast: Leakage from EBS



Head on engineered barrier system

99% of realizations were less than 6.27E2 litre/day

95% of realizations were less than 4.02E2 litre/day

90% of realizations were less than 2.69E2 litre/day

50% of realizations were less than 7.12E1 litre/day

10% of realizations were less than 1.15E1 litre/day

5% of realizations were less than 6.89E0 litre/day

1% of realizations were less than 2.3E0 litre/day

LandSim: Release 1.08

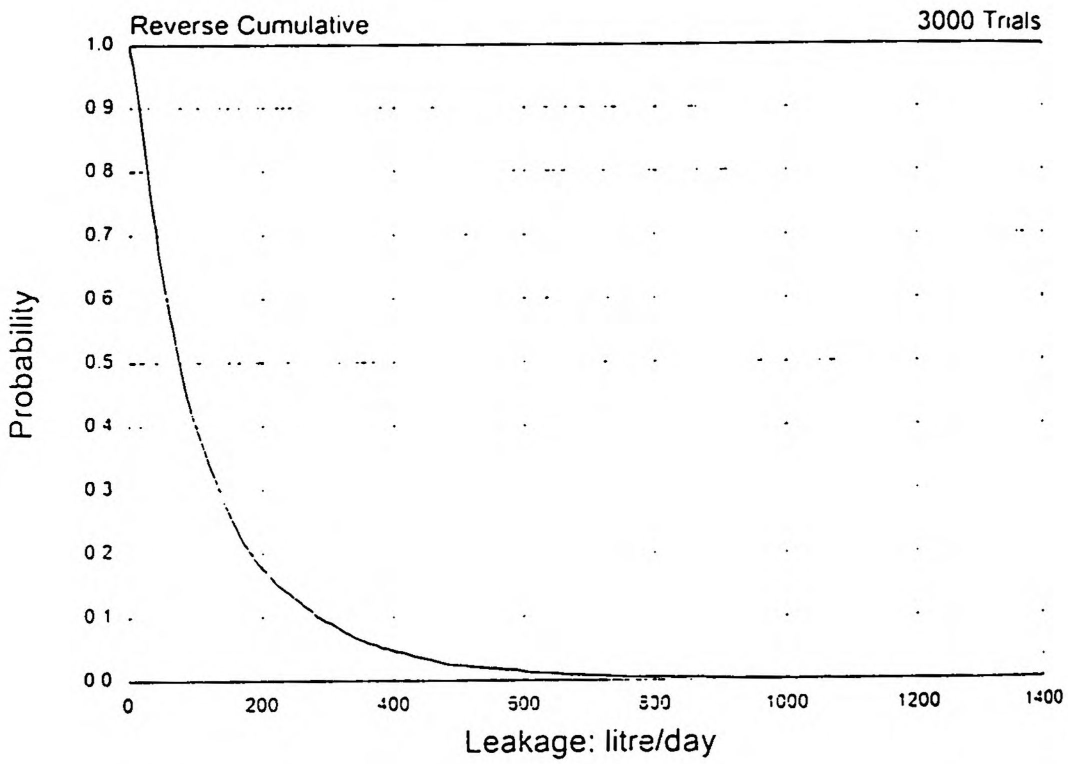
Project Name : [redacted]Encapsulation Cell - First Barrier

Project Number : BEECF048

Client : [redacted]CBC

C:\LANDSIM\[redacted]1.SIM 09/12/99 19:02:26

Forecast: Leakage from EBS



Infiltration Information

Water entering landfill through top (mm/year): normal distribution.

Mean:	16.26
Standard deviation:	0

Justification for Specified Infiltration
From leakage of [redacted]1.SIM

Barrier Information

Justification for Engineered Barrier Type
Unjustified change made to LandSim default

There is single a clay barrier

Design thickness of clay:	0.3 (m)
Variability in thickness of clay:	5 (%)

Justification for Liner Thickness
Values from Drawing No. QA 89/5055 and licence details

Hydraulic conductivity of liner (m/s): log. triangular distribution

Minimum value:	1.0E-10
Most likely value:	1.0E-9
Maximum value:	1.0E-8

Justification for Hydraulics Properties
Use default from LandSim user manual

Unsaturated pathway parameters

Modelled as unsaturated pathway
Pathway length (m): uniform distribution.

Minimum length:	0
Maximum length:	1
Flow Model:	porous medium

Pathway moisture content (%): uniform distribution

Minimum moisture content:	1
Maximum moisture content:	30

Justification for Geometry
Unjustified change made to LandSim default

Pathway porosity (m/s): uniform distribution.

Minimum porosity:	1
Maximum porosity:	1

Pathway hydraulic conductivity values (m/s): log. triangular distribution.

Minimum:	1.0E-10
Likely:	1.0E-7
Maximum:	1.0E-4

Justification for Hydraulics Properties
Unjustified change made to LandSim default

Pathway longitudinal dispersivity (m): log. uniform distribution.

Minimum dispersivity	0.0000000001
Maximum dispersivity	0.1

Pathway transverse dispersivity (m): log. uniform distribution.

Minimum dispersivity:	0
Maximum dispersivity:	0.01

Justification for Dispersion Properties
Values based on Longitudinal D = 0.1 x Pathway Length; Transverse D = 0.1 x Longitudinal

Cation exchange capacity (meq/kg): triangular distribution.

Minimum CEC:	0.0
Likely CEC:	0.1
Maximum CEC:	0.2

Justification for CEC Sorption Parameters
Use default from LandSim user manual

Minimum reaction efficiency:	0.25
Likely reaction efficiency:	0.35
Maximum reaction efficiency:	0.4

Justification for Reaction Efficiency
Use default from LandSim user manual

Vertical pathway parameters

Modelled as vertical pathway
Pathway length (m): uniform distribution.

Minimum length:	0
Maximum length:	10

Pathway porosity (m/s): uniform distribution.

Minimum porosity:	0.1
Maximum porosity:	0.5

Justification for Geometry
Use default from LandSim user manual

Pathway hydraulic conductivity values (m/s): log. triangular distribution.

Minimum:	1.0E-9
Likely:	1.0E-7
Maximum:	1.0E-5

Justification for Hydraulics Properties
Use default from LandSim user manual

Pathway dispersivity (m): log. uniform distribution.

Minimum dispersivity	0.0000000001
Maximum dispersivity	1

Pathway transverse dispersivity (m): log. uniform distribution.

Minimum dispersivity:	0
Maximum dispersivity:	0.1

Justification for Dispersion Details
Use default from LandSim user manual

Aquifer pathway parameters

Modelled as aquifer pathway.

Pathway length (m): uniform distribution.

Minimum length:	100
Maximum length:	1000

Pathway width (m): uniform distribution.

Minimum width:	50
Maximum width:	200

Mixing zone (m): uniform distribution.

Minimum depth:	1
Maximum depth:	10

Pathway porosity (m/s): uniform distribution.

Minimum porosity:	0.1
Maximum porosity:	0.5

Justification for Geometry

Use default from LandSim user manual

Pathway regional gradient: triangular distribution.

Minimum gradient:	0.01
Likely gradient:	0.05
Maximum gradient:	0.05

Pathway hydraulic conductivity values (m/s): log. triangular distribution.

Minimum	1.0E-6
Likely	1.0E-5
Maximum	1.0E-4

Justification for Hydraulics Properties

Use default from LandSim user manual

Pathway longitudinal dispersivity (m): log. uniform distribution.

Minimum dispersivity:	10
Maximum dispersivity:	100

Pathway transverse dispersivity (m): log. uniform distribution

Minimum dispersivity:	1
Maximum dispersivity:	10

Justification for Dispersion Details

Use default from LandSim user manual

Retardation parameters for Unsaturated pathway

Modelled as unsaturated pathway.

No retardation values used in this simulation.
Check 'Unretarded Contaminant Transport' setting under simulation preferences.

Retardation parameters for Vertical pathway

Modelled as vertical pathway.

No retardation values used in this simulation.
Check 'Unretarded Contaminant Transport' setting under simulation preferences.

Retardation parameters for Aquifer pathway

Modelled as aquifer pathway.

No retardation values used in this simulation.
Check 'Unretarded Contaminant Transport' setting under simulation preferences.

Source concentrations of contaminants

All units in milligrams per litre
Uncertainty as logarithmic triangular distribution
Infinite source term

	Minimum	Likely	Maximum
copper	0.0000296	0.000573	0.0268
Cyanide	0.00014	0.003	0.171
Amm as N	0.00312	0.0481	1.67
Phenols	0.000004	0.000086	0.00515

Justification for Contaminant Properties
Output from [redacted]1.SIM

Concentration of copper in biosphere

At 30 years
- 1% of 3000 iterations were less than 1.0E-30 mg/l
- 5% of 3000 iterations were less than 1.0E-30 mg/l
- 10% of 3000 iterations were less than 1.0E-30 mg/l
- 50% of 3000 iterations were less than 1.0E-30 mg/l
- 90% of 3000 iterations were less than 1.17E-8 mg/l
- 95% of 3000 iterations were less than 4.52E-6 mg/l
- 99% of 3000 iterations were less than 5.6E-5 mg/l

At 100 years
- 1% of 3000 iterations were less than 1.0E-30 mg/l
- 5% of 3000 iterations were less than 1.0E-30 mg/l
- 10% of 3000 iterations were less than 1.0E-30 mg/l
- 50% of 3000 iterations were less than 1.07E-11 mg/l
- 90% of 3000 iterations were less than 4.68E-5 mg/l
- 95% of 3000 iterations were less than 1.05E-4 mg/l
- 99% of 3000 iterations were less than 3.57E-4 mg/l

At 300 years
- 1% of 3000 iterations were less than 1.0E-30 mg/l
- 5% of 3000 iterations were less than 2.2E-7 mg/l
- 10% of 3000 iterations were less than 8.17E-7 mg/l
- 50% of 3000 iterations were less than 1.33E-5 mg/l
- 90% of 3000 iterations were less than 1.52E-4 mg/l
- 95% of 3000 iterations were less than 2.84E-4 mg/l
- 99% of 3000 iterations were less than 7.91E-4 mg/l

At 1000 years
- 1% of 3000 iterations were less than 2.73E-7 mg/l
- 5% of 3000 iterations were less than 7.37E-7 mg/l
- 10% of 3000 iterations were less than 1.41E-6 mg/l
- 50% of 3000 iterations were less than 1.57E-5 mg/l
- 90% of 3000 iterations were less than 1.71E-4 mg/l
- 95% of 3000 iterations were less than 3.22E-4 mg/l
- 99% of 3000 iterations were less than 9.2E-4 mg/l

At infinity
- 1% of 3000 iterations were less than 2.73E-7 mg/l
- 5% of 3000 iterations were less than 7.37E-7 mg/l
- 10% of 3000 iterations were less than 1.41E-6 mg/l
- 50% of 3000 iterations were less than 1.57E-5 mg/l
- 90% of 3000 iterations were less than 1.72E-4 mg/l
- 95% of 3000 iterations were less than 3.24E-4 mg/l
- 99% of 3000 iterations were less than 9.2E-4 mg/l

Concentration of Cyanide in biosphere

At 30 years
- 1% of 3000 iterations were less than 1.0E-30 mg/l
- 5% of 3000 iterations were less than 1.0E-30 mg/l
- 10% of 3000 iterations were less than 1.0E-30 mg/l
- 50% of 3000 iterations were less than 1.0E-30 mg/l
- 90% of 3000 iterations were less than 5.41E-8 mg/l
- 95% of 3000 iterations were less than 2.12E-5 mg/l
- 99% of 3000 iterations were less than 2.49E-4 mg/l

At 100 years
- 1% of 3000 iterations were less than 1.0E-30 mg/l
- 5% of 3000 iterations were less than 1.0E-30 mg/l
- 10% of 3000 iterations were less than 1.0E-30 mg/l
- 50% of 3000 iterations were less than 1.17E-10 mg/l
- 90% of 3000 iterations were less than 2.43E-4 mg/l
- 95% of 3000 iterations were less than 5.46E-4 mg/l
- 99% of 3000 iterations were less than 2.61E-3 mg/l

At 300 years
- 1% of 3000 iterations were less than 1.0E-30 mg/l
- 5% of 3000 iterations were less than 1.08E-6 mg/l
- 10% of 3000 iterations were less than 4.4E-6 mg/l
- 50% of 3000 iterations were less than 7.0E-5 mg/l
- 90% of 3000 iterations were less than 9.95E-4 mg/l
- 95% of 3000 iterations were less than 1.94E-3 mg/l
- 99% of 3000 iterations were less than 5.64E-3 mg/l

At 1000 years
- 1% of 3000 iterations were less than 1.46E-6 mg/l
- 5% of 3000 iterations were less than 3.98E-6 mg/l
- 10% of 3000 iterations were less than 7.31E-6 mg/l
- 50% of 3000 iterations were less than 8.29E-5 mg/l
- 90% of 3000 iterations were less than 1.13E-3 mg/l
- 95% of 3000 iterations were less than 2.24E-3 mg/l
- 99% of 3000 iterations were less than 6.46E-3 mg/l

At infinity
- 1% of 3000 iterations were less than 1.46E-6 mg/l
- 5% of 3000 iterations were less than 3.99E-6 mg/l
- 10% of 3000 iterations were less than 7.33E-6 mg/l
- 50% of 3000 iterations were less than 8.3E-5 mg/l
- 90% of 3000 iterations were less than 1.13E-3 mg/l
- 95% of 3000 iterations were less than 2.25E-3 mg/l
- 99% of 3000 iterations were less than 6.46E-3 mg/l

Concentration of Amm as N in biosphere

At 30 years
1% of 3000 iterations were less than 1.0E-30 mg/l
5% of 3000 iterations were less than 1.0E-30 mg/l
10% of 3000 iterations were less than 1.0E-30 mg/l
50% of 3000 iterations were less than 1.0E-30 mg/l
90% of 3000 iterations were less than 7.46E-7 mg/l
95% of 3000 iterations were less than 3.84E-4 mg/l
99% of 3000 iterations were less than 6.23E-3 mg/l
At 100 years
1% of 3000 iterations were less than 1.0E-30 mg/l
5% of 3000 iterations were less than 1.0E-30 mg/l
10% of 3000 iterations were less than 1.0E-30 mg/l
50% of 3000 iterations were less than 9.39E-10 mg/l
90% of 3000 iterations were less than 4.12E-3 mg/l
95% of 3000 iterations were less than 7.99E-3 mg/l
99% of 3000 iterations were less than 2.73E-2 mg/l
At 300 years
1% of 3000 iterations were less than 1.0E-30 mg/l
5% of 3000 iterations were less than 1.85E-5 mg/l
10% of 3000 iterations were less than 8.09E-5 mg/l
50% of 3000 iterations were less than 1.17E-3 mg/l
90% of 3000 iterations were less than 1.17E-2 mg/l
95% of 3000 iterations were less than 2.19E-2 mg/l
99% of 3000 iterations were less than 6.49E-2 mg/l
At 1000 years
1% of 3000 iterations were less than 2.74E-5 mg/l
5% of 3000 iterations were less than 7.63E-5 mg/l
10% of 3000 iterations were less than 1.35E-4 mg/l
50% of 3000 iterations were less than 1.35E-3 mg/l
90% of 3000 iterations were less than 1.37E-2 mg/l
95% of 3000 iterations were less than 2.55E-2 mg/l
99% of 3000 iterations were less than 7.12E-2 mg/l
At infinity
1% of 3000 iterations were less than 2.74E-5 mg/l
5% of 3000 iterations were less than 7.63E-5 mg/l
10% of 3000 iterations were less than 1.35E-4 mg/l
50% of 3000 iterations were less than 1.35E-3 mg/l
90% of 3000 iterations were less than 1.38E-2 mg/l
95% of 3000 iterations were less than 2.57E-2 mg/l
99% of 3000 iterations were less than 7.12E-2 mg/l

Concentration of Phenols in biosphere

At 30 years
- 1% of 3000 iterations were less than 1.0E-30 mg/l
- 5% of 3000 iterations were less than 1.0E-30 mg/l
- 10% of 3000 iterations were less than 1.0E-30 mg/l
- 50% of 3000 iterations were less than 1.0E-30 mg/l
- 90% of 3000 iterations were less than 2.17E-9 mg/l
- 95% of 3000 iterations were less than 6.87E-7 mg/l
- 99% of 3000 iterations were less than 1.06E-5 mg/l

At 100 years
- 1% of 3000 iterations were less than 1.0E-30 mg/l
- 5% of 3000 iterations were less than 1.0E-30 mg/l
- 10% of 3000 iterations were less than 1.0E-30 mg/l
- 50% of 3000 iterations were less than 8.16E-13 mg/l
- 90% of 3000 iterations were less than 7.65E-6 mg/l
- 95% of 3000 iterations were less than 1.78E-5 mg/l
- 99% of 3000 iterations were less than 6.65E-5 mg/l

At 300 years
- 1% of 3000 iterations were less than 1.0E-30 mg/l
- 5% of 3000 iterations were less than 2.7E-8 mg/l
- 10% of 3000 iterations were less than 1.42E-7 mg/l
- 50% of 3000 iterations were less than 2.06E-6 mg/l
- 90% of 3000 iterations were less than 2.57E-5 mg/l
- 95% of 3000 iterations were less than 5.3E-5 mg/l
- 99% of 3000 iterations were less than 1.83E-4 mg/l

At 1000 years
- 1% of 3000 iterations were less than 4.0E-8 mg/l
- 5% of 3000 iterations were less than 1.34E-7 mg/l
- 10% of 3000 iterations were less than 2.33E-7 mg/l
- 50% of 3000 iterations were less than 2.43E-6 mg/l
- 90% of 3000 iterations were less than 3.01E-5 mg/l
- 95% of 3000 iterations were less than 5.88E-5 mg/l
- 99% of 3000 iterations were less than 2.16E-4 mg/l

At infinity
- 1% of 3000 iterations were less than 4.0E-8 mg/l
- 5% of 3000 iterations were less than 1.34E-7 mg/l
- 10% of 3000 iterations were less than 2.33E-7 mg/l
- 50% of 3000 iterations were less than 2.43E-6 mg/l
- 90% of 3000 iterations were less than 3.03E-5 mg/l
- 95% of 3000 iterations were less than 5.92E-5 mg/l
- 99% of 3000 iterations were less than 2.16E-4 mg/l

—Head on engineered barrier system

99% of realizations were less than 4.0E2 litre/day

95% of realizations were less than 4.0E2 litre/day

90% of realizations were less than 4.0E2 litre/day

50% of realizations were less than 4.0E2 litre/day

10% of realizations were less than 2.18E2 litre/day

5% of realizations were less than 1.65E2 litre/day

1% of realizations were less than 1.12E2 litre/day

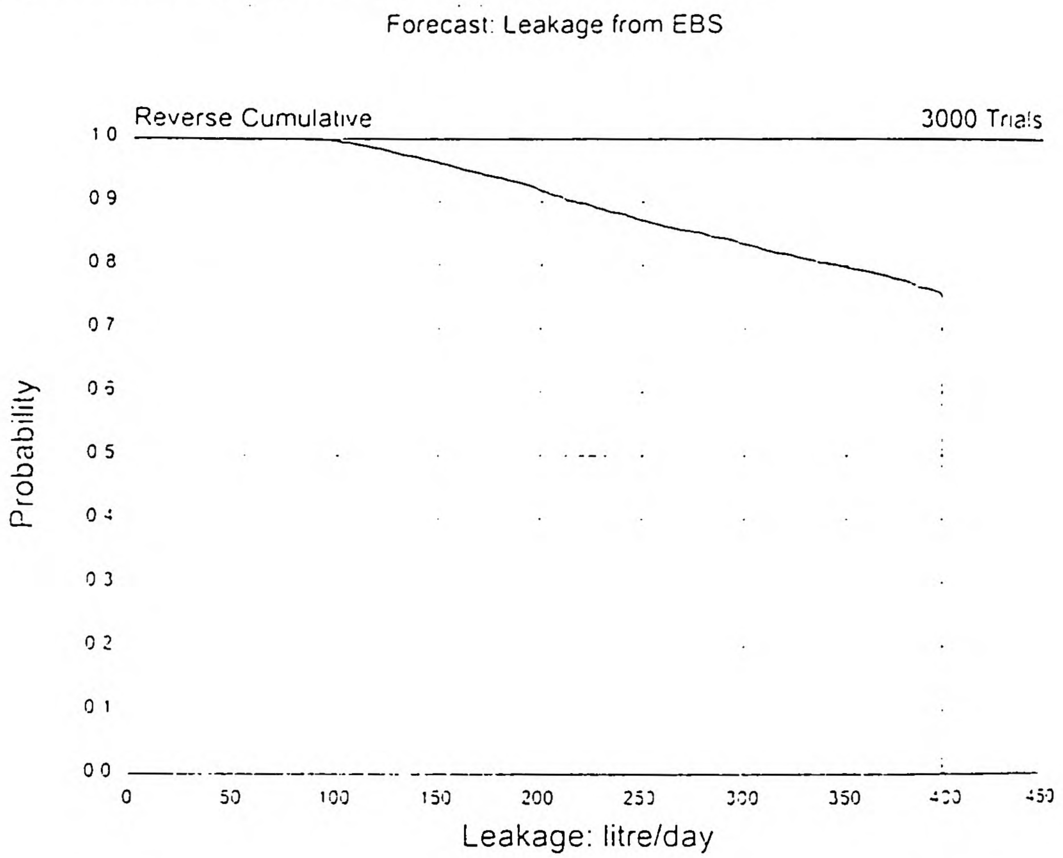
LandSim: Release 1.08

Project Name : [redacted]single clay

Project Number : Risk 0000

Client : [redacted]

C:\LANDSIM\[redacted]2A.SIM 16/12/99 09:29:04



A Parsons Brinckerhoff Company

CALCULATION SHEET

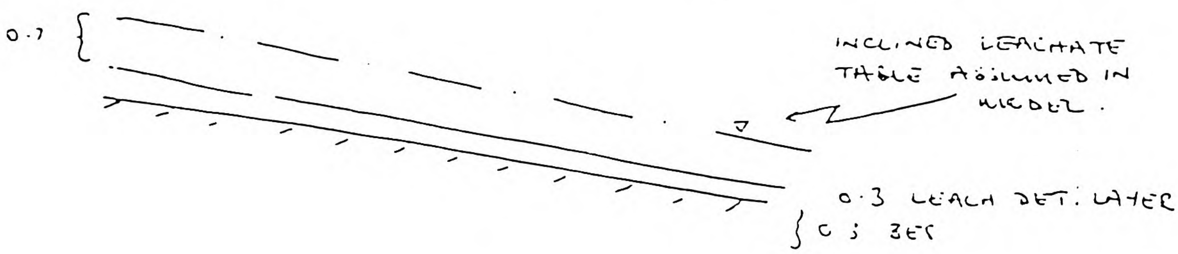
Contract Title	[redacted] RISK ASSESSMENT	Job No	BECC/FC48/C30
Subject	LEAKAGE THROUGH LEACHATE DETECTION LAYER	Drawing No	
Calc. by	ACDG	Date 17.12.99.	Dept Ref
Checked by	D	Date 20th Dec '99	Calc Sheet 1 of 2.

LANDSIM (v.1 CS) assumes that long-term leakage through base of encapsulation cell ≡ long-term leakage through HDPE/BES composite 'upper liner'

→ ie no extraction taking place from leachate detection layer

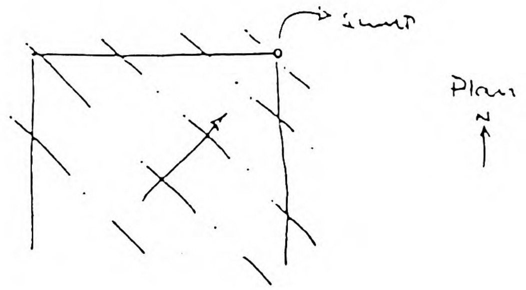
This because model assumes 1m head across whole of base of site owing to reduced efficiency of drainage layer

ie

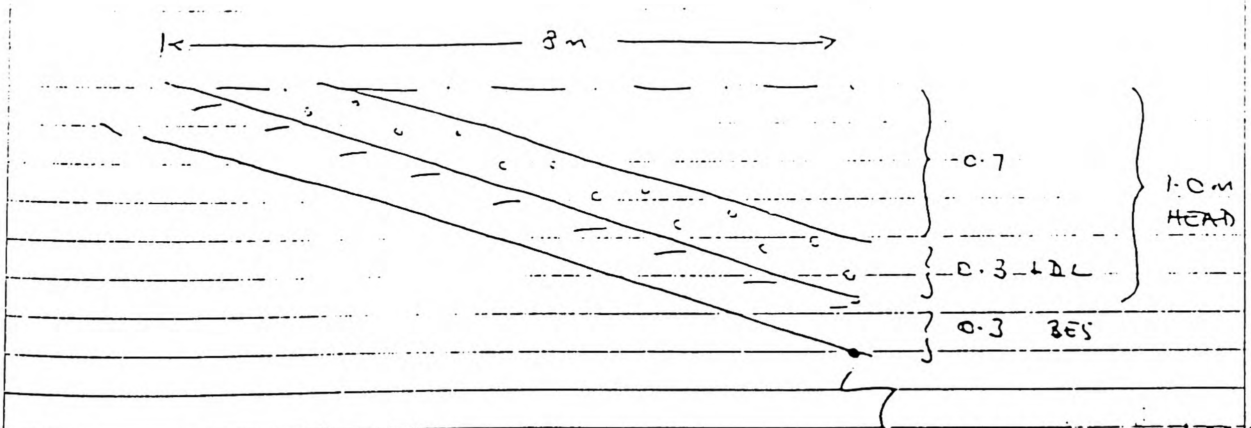


Assuming leachate detection layer is efficient, leakage as follows:

→ Leachate table = horizontal



Grade on base of cell = 1:8
(see Dwg No SC QA 37/5069)

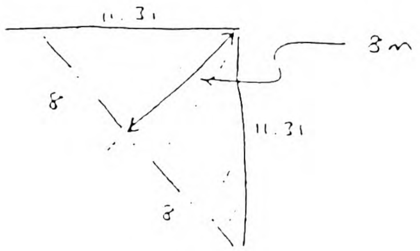


A – maximum head $= \left(\frac{1.3}{0.3}\right) = 4.333'$

A Parsons Brinckerhoff Co

CALCULATION SHEET

Contract Title	[redacted]	Job No	BECLFC45/030
Subject	LEAKAGE THROUGH L. DET. LAYER	Drawing No	
Calc by	ACDG	Date 17.12.99	Dept Ref
Checked by	D	Date 20th DEC '99	Calc Sheet 2 of 2



∴ leachate in contact with $\frac{1}{2} \cdot 16 \cdot 8 = 64 m^2$ BES.

Permeability of BES in site licence $= 10^{-9}$ m/sec.

Av. head on lower BES $= \frac{1}{2} \cdot (1.3/0.3) = 2.1666'$

Area $= 64 m^2$

∴ Flow (daily) $= (10^{-9} \cdot 24 \cdot 3600) \cdot 64 \cdot (2.1666')$

$= 0.01198\ m^3/day$

$\cong 11.98$ l/day

APPENDIX 5

Specimen Construction Quality Assurance (CQA) Monitoring Proformas

CLIENT	BIFFA WASTE SERVICES LTD			JOB No:	
SCHEME	LINER INSTALLATION, WELFORD LANDFILL SITE				
DATE		CHECKING ENGINEER			
STAGE 1	FML DELIVERY AND STORAGE				
ARUP ROLL No		ROLL CODE		ZONE	

QA/QC PROGRAMME CHECKLIST	Y/N	REMARKS IF APPROPRIATE
CONTRACTORS QA/QC PROGRAM IMPLEMENTED		
STAGE SUBMITTALS RECEIVED		
ADEQUATE WORKING EQUIPMENT		
ADEQUATELY TRAINED PERSONNEL/ PROPERLY CLOTHED		
WEATHER : CALM,MILD,DRY		
FML TYPE CONFIRMED-HDPE(2.5mm)		
ROLL THICKNESS-RANDOM CHECK		
ROLL RANDOM SAMPLED-TENSILE TESTING		
DELIVERY DOCUMENTATION RECEIVED		
NO DAMAGE ON DELIVERY		
NO DAMAGE DURING UNLOADING/STORAGE		
STORAGE AREA ADEQUATE/SECURE		
ROLL CORRECTLY STORED		
ROLLS CHECKED AGAINST LAYOUT PLAN		
OTHER COMMENTS		

SIGNED: DATED:	SIGNED: DATED:
FOR BIFFA / INSTALLER	FOR OVE ARUP AND PARTNERS

CLIENT	BIFFA WASTE SERVICES LTD			JOB No:	
SCHEME	LINER INSTALLATION, WELFORD LANDFILL SITE				
DATE		CHECKING ENGINEER			
STAGE 2	LINER SUBGRADE / SUPPORT SURFACE				
ARUP ROLL No		ROLL CODE		ZONE	

QA/QC PROGRAMME CHECKLIST	Y/N	REMARKS IF APPROPRIATE
CONTRACTORS QA/QC PROGRAM IMPLEMENTED		
STAGE SUBMITTALS RECEIVED		
ADEQUATE WORKING EQUPIMENT		
ADEQUATELY TRAINED PERSONNEL/ PROPERLY CLOTHED		
WEATHER : CALM,MILD,DRY		
VEGETATION/ROOTS REMOVED		
ANIMAL BURROWS REMOVED		
HERBICIDE APPLIED		
SURFACE COMPACTED/ROLLED		
DENSITY TESTS COMPLETED/APPROVED		
ROCKS/DEPRESSIONS/SOFT SPOTS REMOVED		
SURFACE APPROVED FOR LINER PLACEMENT		

SIGNED: DATED:	SIGNED: DATED:

FOR BIFFA / INSTALLER

FOR OVE ARUP AND PARTNERS

CLIENT	BIFFA WASTE SERVICES LTD			JOB No:	
SCHEME	LINER INSTALLATION , WELFORD LANDFILL SITE				
DATE		CHECKING ENGINEER			
STAGE 3	PLACEMENT OF LINER				
ARUP ROLL No		ROLL CODE		ZONE	

QA/QC PROGRAMME CHECKLIST	Y/N	REMARKS IF APPROPRIATE
CONTRACTORS QA/QC PROGRAM IMPLEMENTED		
STAGE SUBMITTALS RECEIVED		
ADEQUATE WORKING EQUIPMENT		
ADEQUATELY TRAINED PERSONNEL/ PROPERLY CLOTHED		
WEATHER : CALM,MILD,DRY		
SHEET LAYOUT PLAN APPROVED		
WORK MATCHED TO SEAMING/COVER		
PLACEMENT MATCHES WIND DIRECTION		
SHEETS HAVE CORRECT OVERLAP (750mm)		
SHEETS PROPERLY WEIGHTED DOWN		
PLACED SHEET FREE OF DEFECTS		
NO SHEET REPAIR NECESSARY		
SURVEYED PROGRESS RECORDED ON PLAN		
OTHER COMMENTS		

SIGNED: DATED:	SIGNED: DATED:
FOR BIFFA / INSTALLER	FOR OVE ARUP AND PARTNERS

CLIENT	BIFFA WASTE SERVICES LTD			JOB No:	
SCHEME	LINER INSTALLATION ,WELFORD LANDFILL SITE				
DATE		CHECKING ENGINEER			
STAGE 4	ANCHOR TRENCHES - TOE				
ARUP ROLL No		ROLL CODE		ZONE	

QA/QC PROGRAMME CHECKLIST	Y/N	REMARKS IF APPROPRIATE
CONTRACTORS QA/QC PROGRAM IMPLEMENTED		
STAGE SUBMITTALS RECEIVED		
ADEQUATE WORKING EQUIPMENT		
ADEQUATELY TRAINED PERSONNEL/ PROPERLY CLOTHED		
WEATHER : CALM,MILD,DRY		
TRENCH DIMENSIONS CORRECT		
TRENCH POSITION CORRECT		
LEADING EDGE WELL FORMED,SMOOTH		
FML PROPERLY INSTALLED		
BACKFILL MATERIAL SUITABLE		
BACKFILL PROPERLY COMPACTED		
NO DAMAGE TO FML		
SURVEYED PROGRESS RECORDED ON PLAN		
OTHER COMMENTS		

SIGNED: DATED:	SIGNED: DATED:
FOR BIFFA/ INSTALLER	FOR OVE ARUP AND PARTNERS

CLIENT	BIFFA WASTE SERVICES LTD		JOB No:
SCHEME	LINER INSTALLATION, WELFORD LANDFILL SITE		
DATE		CHECKING ENGINEER	
STAGE 5	COVER OPERATIONS		
ARUP ROLL No		ROLL CODE		ZONE	

QA/QC PROGRAMME CHECKLIST	Y/N	REMARKS IF APPROPRIATE
CONTRACTORS QA/QC PROGRAM IMPLEMENTED		
STAGE SUBMITTALS RECEIVED		
ADEQUATE WORKING EQUPIMENT		
ADEQUATELY TRAINED PERSONNEL/ PROPERLY CLOTHED		
WEATHER : CALM,MILD,DRY		
COVER MATERIAL OF CORRECT GRADING		
ACCESS AND DEPOSITION POINTS VARIED		
COVER DEPTH PROFILES IN PLACE		
COVER PLACEMENT OBSERVED		
FML DEFECTS REPAIRED/RE-TESTED		
EARTHWORK PROFILES REMOVED		
PIPELINE COVER DETAILS COMPLETED		
SURVEYED PROGRESS RECORDED ON PLAN		
OTHER COMMENTS		

SIGNED: DATED:	SIGNED: DATED:

FOR BIFFA / INSTALLER

FOR OVE ARUP AND PARTNERS

Certificate of Acceptance of Slope by Installer

Installer's details

Name :

Authorised Representative :

Project details

Project: Welford landfill site, Northhamptonshire

August 1993

Employer: Biffa Waste Services Limited

The undersigned .... certifies that he is a representative of

.... Ltd, duly authorised to execute this certificate, that he

visually inspected the slope surface described above on .... 1993 and

found the surface to be acceptable for HDPE Liner Placement.

This certificate is based on observations of the surface of the slope only. No subsurface

inspections or tests have been performed and.. Ltd

makes no representations or warranties regarding conditions which may exist below the

surface of the slope.

Date :

Signature :

Name :

Title :

Received by the Engineer's Representative :

Signature :

Name :

Title :

APPENDIX 6

Layout of Postal Questionnaire

GLAMORGAN UNIVERSITY

ARUP

STATUS
O Pilot
● Main
FEB '95

K. C. DAVIES - MASTER OF PHILOSOPHY RESEARCH
LANDFILLS - CONTAINMENT AND CAPPING SYSTEMS

(NOTE: MULTIPLE CHOICE SELECTIONS ACCEPTABLE)

Landfill Name

PAGE 1

Waste Disposal Authority

Operator

Site Licence Ref.

SITEFILE Ranking

UK Grid Reference

LICENCE

1 Valid Post May '94
☐ yes ☐ no

WASTE TYPE & DESIGN

2 Waste Type
☐ inert
☐ municipal
☐ special
☐ co-disposal

3 Void Space Millions cu.m.
☐ 0.5-1
☐ 1-2
☐ 2-5
☐ 5-10
☐ >10

4 Design Concept
LATEST AND FUTURE PHASES
☐ landraise
☐ mineral void
☐ cellular filling
☐ dilute and disperse
☐ containment
☐ other....................?

BASE AND CAPPING SEALS

LATEST AND FUTURE PHASES

Basal Seal
☐ none
☐ synthetic (plastic) liner
☐ bentonite mat
☐ mineral (eg clay etc.)
☐ bentonite enhanced soil
☐ reconditioned natural soil
☐ composite (ie synthetic/mineral)
☐ other...?

6 Capping Layer
☐ no low permeability cap
☐ synthetic (plastic) cap
☐ bentonite mat
☐ mineral (eg clay)
☐ bentonite enhanced soil
☐ reconditioned natural soil
☐ composite(synthetic/mineral)
☐ other...................................?

7 Low Grade Waste Used?
☐ no
☐ in base system
☐ in cap system

8 If Base, Which Waste?
☐ pulverised fuel ash
☐ colliery shale
☐ china clay waste
☐ gravel washery silts
☐ other ....?

9 If Cap, Which Waste?
☐ pulverised fuel ash
☐ colliery shale
☐ china clay waste
☐ gravel washery silts
☐ other.......................?

LEACHATE AND GAS

LATEST AND FUTURE PHASES

10 Leachate Management
☐ none
☐ public sewer
☐ consented outfall
☐ tanker collection
☐ recirculation
☐ on- site treatment
☐ other......................?

11 Gas Management
☐ passive, through cap
☐ passive, vented
☐ active, to flare
☐ active, to turbine(energy)
☐ other.......................?

13 If Yes, Which System?
☐ basal seal
☐ capping
☐ leachate
☐ gas

12 System Failures?
☐ often
☐ occasional
☐ never

15 If Yes, Which Pollutant?
☐ leachate
☐ gas

14 Pollutant Migration?
☐ yes
☐ no

16 Failure Retrievable?
☐ yes
☐ no

17 Pollution Contained?
☐ yes
☐ no

FUTURE POLICY

18 Tipping Life: this site, Post 1995
☐ 0 years
☐ 1-2 years
☐ 2-5 years
☐ 5-10 years
☐ >10 years

19 Future Company :Authority Disposal Policy
☐ minimisation
☐ recycling
☐ composting
☐ incineration
☐ digestion
☐ landfill
☐ transfer
☐ other............?

20 If Landfill, Design Preference?
☐ dilute and disperse
☐ containment
☐ co-disposal

22 Disposal Within Authority?
☐ yes
☐ no
☐ miles.1-way
TYPICAL MEAN

21 Disposal Company
☐ LAWDC
☐ NAWDC
☐ Joint Venture
☐ not confirmed

PLEASE EXPAND ON ANY AREA IN THE COMMENT BOXES PROVIDED ON PAGE 2.

GLAMOROGAN UNIVERSITY

ARUP

K. C. DAVIES - MASTER OF PHILOSOPHY RESEARCH
LANDFILLS - CONTAINMENT AND CAPPING SYSTEMS

Landfill Name

Waste Disposal Authority

Operator

Site Licence Ref.

Valid Post May '94 ☐ yes ☐ no

UK Grid Reference

WASTE TYPE & DESIGN (COMMENTS ACCEPTED ON PAST, CURRENT & FUTURE PHASES - PLEASE INDICATE)

BASE AND CAPPING SEALS (COMMENTS ACCEPTED ON PAST, CURRENT & FUTURE PHASES - PLEASE INDICATE)

LEACHATE AND GAS (COMMENTS ACCEPTED ON PAST, CURRENT & FUTURE PHASES - PLEASE INDICATE)

FUTURE POLICY (COMMENTS ACCEPTED ON PAST, CURRENT & FUTURE PHASES - PLEASE INDICATE)

PLEASE EXPAND ON ANY AREA IN THE COMMENT BOXES PROVIDED ON PAGE 2.

THANK YOU FOR COMPLETING THIS QUESTIONNAIRE. THE INFORMATION YOU HAVE PROVIDED WILL BE TREATED IN STRICT CONFIDENCE AND FOR THE PURPOSE OF THIS ACADEMIC RESEARCH PROJECT ONLY.

APPENDIX 7

Listing of Questionnaire Returns

Grid Re	Waste t	Licen	Waste T	Site He	Void Sp	Design Co	Basal Seal	Capping La	Use o	Il Base	
SJ 27 64	Alyn & Deeside District Council	yes	municipal special	**** inc. H	1-2	mineral void containment	mineral (eg clay etc.)	composite(synthetic/ mineral)	no	nil data	ni
SJ 27 64	Alyn & Deeside District Council	no	nil data	**** inc. H	nil data		mineral (eg clay)				
SJ 31 69	Alyn & Deeside District Council	yes	alternative	**** inc. H	nil data	landraise	none	no cap(but soil/shale cover) not confirmed	no	nil data	nil
SH 501 539	Arfon Borough Council	yes	municipal	**** inc. H	5-10	dilute and disperse containment	none bentonite mat	no cap(but soil/shale cover)	nil data	nil data	nil
ST 410 686	Avon County Council	nil data	nil data	*** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
ST 702 805	Avon County Council	yes	inert co-disposal	*** inc. H	nil data	dilute and disperse other	reconditioned natural soil/clay	reconditioned natural soil	nil data	nil data	nil
ST 600 880	Avon County Council	yes	municipal co-disposal	**** inc. H	1-2	mineral void dilute and disperse containment	none geomembrane mineral (eg clay etc.) composite (ie	no cap(but soil/shale cover) mineral (eg clay)	no	nil data	nil
ST 555 806	Avon County Council	yes	inert municipal	*** inc. H	less than one	landraise cellular filling containment	mineral (eg clay etc.)	mineral (eg clay) reconditioned natural soil	no	nil data	nil
nil data	Avon County Council	yes	inert municipal special co-disposal	nil data	1-2	landraise containment	none	mineral (eg clay)	no	nil data	nil
ST 764 604	Avon County Council	nil data	nil data	*** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
TL 211 488	Bedfordshire County Council	yes	inert municipal	*** inc. H	1-2	mineral void dilute and disperse	none	reconditioned natural soil	no	nil data	nil
TL 015 425	Bedfordshire County Council	yes	inert municipal special co-disposal	**** inc. H	more than ten	mineral void cellular filling containment	mineral (eg clay etc.)	mineral (eg clay)	no	nil data	nil
TL 038 280	Bedfordshire County Council	yes	inert municipal	**** inc. H	2-5	landraise mineral void dilute and disperse	none	reconditioned natural soil	no	nil data	nil
TL 044 467	Bedfordshire County Council	yes	inert municipal	**** inc. H	5-10	mineral void cellular filling containment	mineral (eg clay etc.)	mineral (eg clay)	no	nil data	nil
SP 965 396	Bedfordshire County Council	yes	inert municipal co-disposal	**** inc. H	more than ten	mineral void cellular filling containment	mineral (eg clay etc.)	mineral (eg clay)	no	nil data	nil
TL 186 352	Bedfordshire County Council	yes	inert municipal	**** inc. H	5-10	mineral void containment	mineral (eg clay etc.)	mineral (eg clay)	no	nil data	nil
SU 605 680	Berkshire County Council	yes	inert municipal	**** inc. H	less than one	mineral void cellular filling containment	mineral (eg clay etc.)	mineral (eg clay)	no	nil data	nil
SU 697 704	Berkshire County Council	no	nil data	*** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
SU 533 648	Berkshire County Council	no	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
SU 500 745	Berkshire County Council	yes	municipal	**** inc. H	less than one	cellular filling containment	composite (ie synthetic/mineral)	mineral (eg clay)	no	nil data	nil
SU 906 776	Berkshire County Council	yes	co-disposal	**** inc. H	2-5	mineral void containment	mineral (eg clay etc.)	mineral (eg clay)	no	nil data	nil
SU 908 772	Berkshire County Council	yes	co-disposal	**** inc. H	less than one	containment	mineral (eg clay etc.)	mineral (eg clay)	no	nil data	nil
SU 702 709	Berkshire County Council	no	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
SU 895 693	Berkshire County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
SO 185 073	Blaenau Gwent Borough Council	yes	inert municipal special co-disposal	**** inc. H	2-5	landraise cellular filling dilute and disperse containment	mineral (eg clay etc.)	composite(synthetic/mi neral)	no	nil data	nil
SU 98 88	Buckinghamshire County Council	yes	co-disposal municipal	**** inc. H	2-5	landraise mineral void	none mineral (eg clay etc.)	mineral (eg clay) reconditioned natural soil	in base system in cap system	overburden waste	oth alter
SU 983 858	Buckinghamshire County Council	yes	municipal	**** inc. H	1-2	mineral void containment	mineral (eg clay etc.)	mineral (eg clay)	no	nil data	nil c
SP 855 320	Buckinghamshire County Council	yes	municipal special	**** inc. H	more than ten	mineral void containment	mineral (eg clay etc.)	mineral (eg clay)	no	nil data	nil d
TQ 02 77	Buckinghamshire County Council	yes	municipal	**** inc. H	1-2	mineral void containment	mineral (eg clay etc.)	mineral (eg clay)	no	nil data	nil d

Leachat	Gas Manager	Syste	If Yes	Poll	If Yes	Failu	Pollu	Tippin	Landfill	Future Poll	Disposal	Dispos
recirculation	active, to flare or process active, to turbine(energy)	occasional	leachate	no	nil data	yes	yes	2-5 years	containment	landfill	LAWDC	yes
none	passive, through cover	occasional	leachate	yes	leachate	yes	yes	2-5 years	containment	minimisation landfill	not confirmed	yes
consented outfall	passive, vented	never	nil data	no	nil data	nil data	nil data	more than ten	containment	minimisation recycling landfill	LAWDC	yes
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	passive, vented	never	nil data	yes	gas	no	yes under review	0 years	containment	transfer	not confirmed	nil data
none consented outfall on- site treatment	passive, through cover passive, vented active, to flare or process active, to	often	leachate gas	yes	leachate gas	yes no	yes no under review	5-10 years	containment	composting incineration landfill transfer	not confirmed	yes no ...... miles, 1-
public sewer	passive, vented	occasional	leachate	yes	leachate	no	no under review	2-5 years	containment	landfill transfer	NAWDC	yes no ...... miles, 1-
public sewer on- site treatment	passive, vented	never	nil data	no	nil data	nil data	yes	2-5 years	containment	landfill	NAWDC	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
none	passive, vented	never	nil data	yes	leachate gas	no	no	5-10 years	dilute and disperse	landfill	NAWDC	nil data
consented outfall recirculation on- site treatment	active, to turbine(energy)	occasional	leachate	yes	leachate	yes	yes	2-5 years	containment co-disposal	landfill	NAWDC	nil data
recirculation	active, to turbine(energy)	occasional	leachate	yes	leachate	yes	nil data	1-2 years	dilute and disperse	minimisation recycling composting transfer	not confirmed	yes
public sewer	active, to turbine(energy)	occasional	gas	yes	gas	yes	yes	1-2 years	containment	minimisation recycling composting landfill transfer	not confirmed	no
recirculation	active, to turbine(energy)	occasional	nil data	yes	gas	yes	yes	2-5 years	containment co-disposal	landfill	NAWDC	nil data
consented outfall recirculation on- site treatment	active, to flare or process	occasional	gas	yes	gas	yes	yes	2-5 years	containment	landfill	NAWDC	nil data
none	active, to flare or process	occasional	gas	yes	gas	yes	yes	0 years	containment co-disposal	recycling incineration landfill	NAWDC	yes
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
none	active, to flare nil data	never	nil data	no	nil data	nil data	nil data	5-10 years	containment	recycling landfill	not confirmed	nil data
recirculation	passive, vented	nil data	nil data	nil data	nil data	nil data	nil data	0 years	co-disposal	minimisation recycling composting landfill	NAWDC	nil data
recirculation	passive, vented	never	nil data	no	nil data	nil data	nil data	0 years	co-disposal	minimisation recycling landfill transfer	NAWDC	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
public sewer	passive, vented active, to turbine(energy)	occasional	leachate	yes	leachate	yes	yes	more than ten	dilute and disperse containment co-disposal	recycling composting landfill	LAWDC	yes
tanker collection	active, to turbine(energy)	occasional	gas	yes	gas	yes	no	5-10 years	containment	nil data	NAWDC	nil data
tanker collection	active, to flare or process	occasional	leachate	maybe	leachate	yes	yes	1-2 years	containment	nil data	NAWDC	nil data
on- site treatment	active, to flare or process	occasional	gas	no	nil data	nil data	yes	more than ten	containment	nil data	NAWDC	nil data
recirculation	passive, vented	never	nil data	no	nil data	nil data	nil data	2-5 years	containment	nil data	NAWDC	nil data

Grid Re	Waste I	Licen	Waste T	Siteme	Void Sp	Design Co	Basal Seal	Capping La	Use o	n Base	n
SU 785 993	Buckinghamshire County Council	no	inert municipal	*** inc. H	less than one	landraise	none	no cap(but soil shale cover)	no	nil data	nil
SU 883 898	Buckinghamshire County Council	yes	municipal	**** inc. H	less than one	landraise	none	no cap(but soil shale cover)	no	nil data	nil
TQ 035 772	Buckinghamshire County Council	yes	inert alternative	**** inc. H	less than one	mineral void	mineral (eg clay etc.)	mineral (eg clay)	no	nil data	nil
SP 690 240	Buckinghamshire County Council	yes	co-disposal municipal	**** inc. H	more than ten	containment	mineral (eg clay etc.)	mineral (eg clay)	no	nil data	nil
TL 408 988	Cambridgeshire County Council	yes	inert municipal alternative	*** inc. H	less than one	landraise cellular filling dilute and disperse containment	none mineral (eg clay etc.) bentonite enhanced soil	mineral (eg clay)	no	nil data	nil
TL 465 625	Cambridgeshire County Council	yes	inert municipal alternative	**** inc. H	1-2	landraise containment	mineral (eg clay etc.)	mineral (eg clay)	no	nil data	nil
TL 480 690	Cambridgeshire County Council	yes	inert municipal alternative	*** inc. H	less than one	landraise mineral void cellular filling containment	mineral (eg clay etc.)	mineral (eg clay)	no	nil data	nil
TL 392 514	Cambridgeshire County Council	yes	burnt residue	**** inc. H	2-5	mineral void cellular filling containment	mineral (eg clay etc.)	mineral (eg clay)	no	nil data	nil
TL 207 685	Cambridgeshire County Council	no	inert municipal special co-disposal alternative	**** inc. H	less than one	mineral void cellular filling dilute and disperse	none	mineral (eg clay)	no	nil data	nil
TL 497 777	Cambridgeshire County Council	yes	inert municipal alternative	*** inc. H	less than one	landraise cellular filling containment	mineral (eg clay etc.)	mineral (eg clay)	no	nil data	nil
TL 374 800	Cambridgeshire County Council	yes	inert municipal alternative	*** inc. H	less than one	mineral void cellular filling containment	mineral (eg clay etc.)	mineral (eg clay)	no	nil data	nil
TF 235 015	Cambridgeshire County Council	yes	inert municipal alternative	**** inc. H	less than one	mineral void cellular filling containment	mineral (eg clay etc.)	mineral (eg clay)	no	nil data	nil
TF 205 020	Cambridgeshire County Council	yes	inert municipal co-disposal alternative	**** inc. H	less than one	mineral void cellular filling containment	mineral (eg clay etc.)	mineral (eg clay)	no	nil data	nil
ST 221 780	Cardiff City Council	yes	municipal	*** inc. H	nil data	landraise dilute and disperse	none	clay no cap(but soil shale cover)	no	nil data	nil
ST 212 780	Cardiff City Council	no	municipal	*** inc. H	2-5	landraise dilute and disperse other	mineral (eg clay) butyl rubber none	clay no cap(but soil shale cover) alternative	no	nil data	nil
SN 483 173	Carmarthen District Council	yes	inert municipal	*** inc. H	less than one	cellular filling containment	mineral (eg clay etc.) composite (ie synthetic:mineral)	synthetic (plastic) cap mineral (eg clay)	no	nil data	nil
SN 611 912	Ceridigion District Council	no	municipal	*** inc. H	nil data	dilute and disperse	mineral (eg clay etc.)	no cap(but soil shale cover)	nil data	nil data	nil
SJ 940 765	Cheshire County Council	yes	inert	*** inc. H	less than one	mineral void	none	no cap(but soil shale cover)	no	nil data	nil
SJ 665 935	Cheshire County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
SJ 573 863	Cheshire County Council	yes	inert municipal special co-disposal	**** inc. H	more than ten	landraise cellular filling containment	geomembrane bentonite enhanced soil	synthetic (plastic) cap	no	nil data	nil c
SJ 443 717	Cheshire County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil c
SJ 678 890	Cheshire County Council	no	co-disposal	**** inc. H	2-5	landraise dilute and disperse	none	mineral (eg clay)	no	nil data	nil d
SJ 901 717	Cheshire County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil d
SJ 716 575	Cheshire County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil d
SJ 678 918	Cheshire County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil d
NZ 564 120	Cleveland County Council	yes	municipal	**** inc. H	nil data	mineral void dilute and disperse	none	mineral (eg clay)	in cap system	nil data	china wast
NZ 605 175	Cleveland County Council	no	municipal	*** inc. H	nil data	landraise dilute and disperse mineral void other	none	no cap(but soil/shale cover)	in cap system	nil data	china waste
NZ 481 278	Cleveland County Council	yes	municipal special	**** inc. H	nil data	mineral void dilute and disperse	none	no cap(but soil/shale cover)	no	nil data	nil d
NZ 495 258	Cleveland County Council	yes	inert municipal special	**** inc. H	nil data	dilute and disperse other	none	no cap(but soil/shale cover)	in cap system	nil data	china waste

Leachat	Gas Manager	Syste	If Yes	Poll	If Yes	Pathw	Poll	Tippin	Landfill	Future Poli	Disposa	Dispos
none	passive, through cover	never	nil data	no	nil data	nil data	nil data	0 years	nil data	nil data	nil data	nil data
none	active, to flare or process	occasional	nil data	yes	gas	yes	yes	1-2 years	containment	nil data	LAWDC	nil data
recirculation	passive, vented	never	nil data	no	nil data	nil data	nil data	1-2 years	containment	nil data	NAWDC	nil data
on-site treatment	active, to turbine(energy)	occasional	gas	yes	gas	yes	yes	more than ten	containment	nil data	NAWDC	nil data
tanker collection recirculation on-site treatment	active, to flare or process	occasional	leachate	yes	leachate	yes	no	1-2 years	containment	landfill	LAWDC	nil data
none	active, to turbine(energy)	never	nil data	nil data	nil data	nil data	yes	more than ten	containment	landfill	LAWDC	nil data
recirculation	passive, vented	occasional	leachate	yes	leachate	yes	yes	2-5 years	containment	landfill	NAWDC	nil data
none	nil data	never	nil data	no	nil data	nil data	yes	more than ten	containment	minimisation	nil data	yes
recirculation on-site treatment	passive, vented	occasional	leachate	yes	leachate	yes	no	0 years	containment	recycling landfill	NAWDC	nil data
tanker collection	passive, vented	occasional	leachate	no	nil data	nil data	nil data	5-10 years	containment	landfill	LAWDC	nil data
none tanker collection	passive, vented	never	nil data	no	nil data	nil data	yes	5-10 years	containment	landfill	NAWDC	nil data
recirculation	passive, vented	occasional	leachate	yes	leachate	yes	yes	2-5 years	containment	landfill	NAWDC	nil data
recirculation	active, to flare or process	occasional	leachate	yes	leachate	yes	yes	2-5 years	containment	recycling composting incineration digestion landfill	NAWDC	nil data
disposal consented outfall	passive, through cover	nil data	nil data	maybe	nil data	under review	under review	more than ten	containment	minimisation recycling composting digestion landfill	LAWDC	yes
disposal consented outfall	passive, through cover	nil data	nil data	maybe	leachate gas	under review	under review	0 years	containment	minimisation recycling composting digestion landfill	Joint Venture	yes
tanker collection	passive, vented	never	nil data	no	nil data	yes	yes	5-10 years	containment	recycling landfill	not confirmed	yes
consented outfall on-site treatment	passive, through cover	never	nil data	no	nil data	nil data	yes	nil data	nil data	nil data	nil data	nil data
none	passive, through cap passive, through cover	never	nil data	no	nil data	nil data	nil data	more than ten	containment	recycling landfill	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
recirculation	passive, vented active, to flare or process	occasional	gas	no	nil data	yes	yes	more than ten	containment	landfill	LAWDC	yes
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
tanker collection	active, to turbine(energy)	occasional	leachate	no	nil data	yes	yes	0 years	containment	minimisation recycling landfill transfer	Joint Venture	yes
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
none	passive, vented	occasional	gas	yes	gas	yes	yes	0 years	containment	minimisation recycling incineration landfill	LAWDC Joint Venture not confirmed	nil data
none	passive, vented	occasional	gas	yes	gas	yes	yes	0 years	containment	minimisation recycling incineration landfill	LAWDC Joint Venture	nil data
none	passive, through cover passive, vented	never	nil data	no	nil data	nil data	yes	1-2 years	containment	minimisation recycling incineration landfill	not confirmed LAWDC Joint Venture	nil data
other..............? alternative	other........................? alternative	nil data	nil data	maybe	nil data	nil data	under review	nil data	containment	minimisation recycling landfill incineration	LAWDC Joint Venture not confirmed	nil data

Grid Re	Waste (	Licen	Waste T	Site Re	Void Sp	Design Co	Basal Seal	Capping La	Use o	Base	
nil data	Colwyn Borough Council	yes	inert	nil data	nil data	nil data	none	no cap(but soil/shale cover)	nil data	nil data	nil
nil data	Colwyn Borough Council	yes	inert	nil data	1-2	other	none	no cap(but soil/shale cover)	no	nil data	nil
SH 898 782	Colwyn Borough Council	yes	municipal	**** inc. H	1-2	mineral void containment	composite (ie synthetic/mineral)	nil data	no	nil data	nil
SW 730 224	Cornwall County Council	no	nil data	*** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
SS 230 098	Cornwall County Council	no	nil data	*** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
SS 232 093	Cornwall County Council	no	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
SW 823 324	Cornwall County Council	no	co-disposal	*** inc. H	nil data	nil data	none	mineral (eg clay)	no	nil data	nil
NY 025 245	Cumbria County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
SD 202 637	Cumbria County Council	yes	inert municipal	**** inc. H	less than one	landraise dilute and disperse	none	bentonite mat	no	nil data	nil
NY 364 632	Cumbria County Council	yes	inert municipal co-disposal	**** inc. H	2-5	landraise cellular filling containment	composite (ie synthetic/mineral)	bentonite mat mineral (eg clay)	no	nil data	nil
NY 800 158	Cumbria County Council	no	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
NY 465 293	Cumbria County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
SD 213 747	Cumbria County Council	yes	inert municipal special co-disposal	**** inc. H	less than one	landraise containment	geomembrane mineral (eg clay etc)	synthetic (plastic) cap reconditioned natural soil	no	nil data	nil
???????????	Cumbria County Council	no	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
NY 025 243	Cumbria County Council	yes	inert municipal special co-disposal	**** inc. H	2-5	mineral void cellular filling containment	mineral (eg clay etc)	mineral (eg clay)	no	nil data	nil
NY 147 484	Cumbria County Council	yes	inert municipal	**** inc. H	less than one	landraise mineral void dilute and disperse	none	synthetic (plastic) cap bentonite enhanced soil	no	nil data	nil
SD 179 792	Cumbria County Council	no	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
NY 800 158	Cumbria County Council	no	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
SD 503 927	Cumbria County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
SD 534 980	Cumbria County Council	no	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
SO 005 054	Cynon Valley Borough Council	yes	municipal	*** inc. H	1-2	dilute and disperse containment	none bentonite enhanced soil	bentonite enhanced soil	in base system in cap system	colliery shale	coll
SK 40 31	Derbyshire County Council	yes	inert municipal special	**** inc. H	1-2	mineral void cellular filling containment	geomembrane mineral (eg clay etc.) bentonite enhanced soil reconditioned natural soil/clay composite (ie	synthetic (plastic) cap mineral (eg clay) reconditioned natural soil composite(synthetic/mineral)	in base system in cap system	pulverised fuel ash	pulv fuel
SK 120 713	Derbyshire County Council	yes	inert municipal special	**** inc. H	less than one	mineral void cellular filling dilute and disperse	none	mineral (eg clay)	no	nil data	nil c
SK 356 543	Derbyshire County Council	yes	inert municipal special	**** inc. H	less than one	mineral void cellular filling containment	mineral (eg clay etc.) reconditioned natural soil/clay	mineral (eg clay) reconditioned natural soil	no	nil data	nil c
SK 153 412	Derbyshire County Council	yes	inert municipal special	**** inc. H	less than one	mineral void dilute and disperse	none	mineral (eg clay)	no	nil data	nil d
SK 280 215	Derbyshire County Council	yes	inert municipal special	**** inc. H	1-2	mineral void cellular filling containment	mineral (eg clay etc.) reconditioned natural soil/clay	mineral (eg clay) reconditioned natural soil	in base system in cap system	colliery shale	colli
SK 43 74	Derbyshire County Council	yes	inert municipal special	**** inc. H	1-2	mineral void cellular filling containment	mineral (eg clay etc.) reconditioned natural soil/clay	mineral (eg clay) reconditioned natural soil	in base system in cap system	colliery shale	colli
SK 466 671	Derbyshire County Council	yes	inert municipal special	**** inc. H	less than one	mineral void cellular filling containment	mineral (eg clay etc.) reconditioned natural soil/clay	mineral (eg clay) reconditioned natural soil	in base system in cap system	colliery shale	colli

Leachat	Gas Manager	Syste	If Yes	Fon	If Yes	and	Fond	Tippin	Landfill	Future	Fon Dispos	Dispose
none	passive, vented	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
recirculation	passive, through cover	never	nil data	nil data	nil data	nil data	nil data	5-10 years	dilute and disperse	nil data	nil data	nil data
recirculation	active, to flare or process	occasional	gas	maybe	gas	yes	yes	more than ten	containment	minimisation recycling landfill	NAWDC	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
none	passive, through cap nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
none	passive, vented	occasional	gas	yes	gas	yes	yes	2-5 years	containment co-disposal	transfer	LAWDC	nil data
tanker collection	active, to turbine(energy)	never	gas	no	nil data	nil data	nil data	5-10 years	containment co-disposal	landfill	LAWDC	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
tanker collection	active, to flare or process	occasional	nil data	no	nil data	nil data	nil data	2-5 years	dilute and disperse co-disposal	landfill	NAWDC	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
public sewer consented outfall on-site treatment	active, to turbine(energy)	never	nil data	no	nil data	nil data	nil data	5-10 years	containment co-disposal	landfill	LAWDC	nil data
none	passive, through cap passive, through cover	never	nil data	no	nil data	nil data	nil data	2-5 years	containment	minimisation landfill	not confirmed	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
none	passive, vented	nil data	nil data	maybe	nil data	nil data	under review	more than ten	containment	landfill	LAWDC	yes
public sewer	passive, vented active, to flare or process	occasional	gas	yes	gas	yes	yes	2-5 years	containment	landfill transfer	NAWDC	yes
none	passive, through cover	never	nil data	yes	leachate gas	no	no	1-2 years	containment	landfill transfer	LAWDC	nil data
none	active, to flare or process active, to turbine(energy)	occasional	gas	yes	gas	yes	yes	0 years	containment	landfill transfer	LAWDC	yes
none	active, to flare or process	occasional	gas	no	nil data	nil data	yes	1-2 years	containment	landfill transfer	LAWDC	yes
none	passive, through cover passive, vented	never	nil data	yes	gas	yes	yes	2-5 years	containment	landfill transfer	LAWDC	yes
none	passive, through cover passive, vented	never	nil data	no	nil data	nil data	yes	2-5 years	containment	landfill transfer	LAWDC	yes
tanker collection recirculation on-site treatment	active, to flare or process	occasional	gas	yes	gas	yes	yes	2-5 years	containment	landfill transfer	LAWDC	yes

Grid Re	Waste I	Licer	Waste T	SiteFile	Void Sp	Design Co	Basal Seal	Capping La	Use o	If Base	Ir
nil data	Devon County Council	yes	inert	**** inc. H	nil data	landraise	none	no cap(but soil/shale cover)	no	nil data	nil
SX 490 877	Devon County Council	yes	municipal	**** inc. H	less than one	mineral void containment	other....................? alternative	mineral (eg clay)	no	nil data	nil
SX 885 740	Devon County Council	yes	municipal	**** inc. H	less than one	mineral void dilute and disperse	none	mineral (eg clay)	no	nil data	nil
SY 205 990	Devon County Council	yes	municipal	**** inc. H	less than one	landraise cellular filling dilute and disperse	none	mineral (eg clay)	no	nil data	nil
SS 530 210	Devon County Council	yes	municipal	**** inc. H	1-2	landraise dilute and disperse containment	none composite (ie synthetic/mineral) geomembrane	synthetic (plastic) cap mineral (eg clay)	no	nil data	nil
SX 513 548	Devon County Council	yes	municipal special co-disposal	**** inc. H	2-5	landraise dilute and disperse	none	synthetic (plastic) cap mineral (eg clay) composite(synthetic/mineral)	no	nil data	nil
SS 471 264	Devon County Council	yes	inert	*** inc. H	nil data	dilute and disperse	none	no cap(but soil/shale cover)	nil data	nil data	nil
SX 783 423	Devon County Council	yes	municipal	**** inc. H	nil data	landraise	none	mineral (eg clay)	no	nil data	nil
SS 793 008	Devon County Council	yes	municipal	**** inc. H	nil data	landraise dilute and disperse	none	mineral (eg clay)	no	nil data	nil
SX 860 763	Devon County Council	yes	municipal	**** inc. H	2-5	mineral void containment	composite (ie synthetic/mineral)	mineral (eg clay)	no	nil data	nil
SN 647 153	Dinefwr Borough Council	no	inert municipal	*** inc. H	less than one	landraise cellular filling containment	mineral (eg clay etc.)	reconditioned natural soil	no	nil data	nil
SY 757 880	Dorset County Council	yes	inert municipal	**** inc. H	nil data	mineral void dilute and disperse	mineral (eg clay etc.)	reconditioned natural soil	no	nil data	nil
SY 485 915	Dorset County Council	yes	municipal	*** inc. H	less than one	mineral void dilute and disperse	mineral (eg clay etc.)	reconditioned natural soil	no	nil data	nil
SZ 030 965	Dorset County Council	yes	inert municipal	**** inc. H	2-5	mineral void dilute and disperse	mineral (eg clay etc.)	mineral (eg clay)	no	nil data	nil
SZ 021 781	Dorset County Council	yes	municipal	*** inc. H	less than one	mineral void	none	reconditioned natural soil	no	nil data	nil
SZ 041 945	Dorset County Council	no	inert	*** inc. H	nil data	mineral void	nil data	nil data	nil data	nil data	nil
SZ 030 965	Dorset County Council	yes	inert municipal	**** inc. H	2-5	mineral void containment	mineral (eg clay etc.)	mineral (eg clay)	no	nil data	nil
ST 867 093	Dorset County Council	no	municipal	*** inc. H	nil data	mineral void dilute and disperse	none	reconditioned natural soil	no	nil data	nil
SY 906 887	Dorset County Council	yes	inert municipal	**** inc. H	nil data	mineral void containment	mineral (eg clay etc.)	mineral (eg clay)	no	nil data	nil d
SY 882 877	Dorset County Council	yes	inert municipal	**** inc. H	nil data	mineral void containment	mineral (eg clay etc.)	mineral (eg clay)	no	nil data	nil d
ST 633 153	Dorset County Council	no	municipal	*** inc. H	nil data	mineral void dilute and disperse	none	reconditioned natural soil	no	nil data	nil d
NZ 287 221	Durham County Council	nil data	nil data	*** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil d
NZ 264 555	Durham County Council	nil data	nil data	*** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil d
NZ 020 363	Durham County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil d
NZ 095 445	Durham County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil d.
NY 940 370	Durham County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil da
NY 970 230	Durham County Council	no	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil da
NZ 188 232	Durham County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil da

Leachat	Gas Manager	Syste	If Yes	Poll	If Yes	Failu	Pollu	Tippin	Landfill	Future Poll	Disposal	Dispos
none	passive, through cover	nil data	nil data	nil data	nil data	nil data	nil data	2-5 years	containment	recycling composting landfill transfer	LAWDC	nil data
recirculation	passive, vented	often	leachate	no	nil data	nil data	nil data	1-2 years	containment	recycling composting landfill transfer	LAWDC	nil data
none	passive, vented	nil data	nil data	nil data	nil data	nil data	nil data	0 years	containment	recycling composting landfill transfer	LAWDC	nil data
none	passive, through cover	nil data	nil data	no	nil data	nil data	nil data	2-5 years	containment	recycling composting landfill transfer	LAWDC	nil data
public sewer recirculation on-site treatment	passive, vented active, to flare or process	occasional	leachate	yes	leachate	yes	yes	5-10 years	containment	recycling composting landfill transfer	LAWDC	nil data
consented outfall	passive, vented active, to flare or process	never	nil data	no	nil data	nil data	nil data	5-10 years	containment	recycling composting landfill transfer	LAWDC	nil data
none	passive, through cover	nil data	nil data	nil data	nil data	nil data	nil data	nil data	containment	recycling landfill	NAWDC	nil data
none	passive, vented	nil data	nil data	nil data	nil data	nil data	nil data	0 years	containment	recycling composting landfill transfer	LAWDC	nil data
none	passive, vented	nil data	nil data	no	nil data	nil data	nil data	1-2 years	containment	recycling composting landfill transfer	LAWDC	nil data
public sewer recirculation	passive, vented active, to flare or process	never	nil data	nil data	nil data	nil data	nil data	more than ten	containment	recycling incineration landfill transfer	NAWDC	nil data
public sewer	passive, vented	occasional	leachate	yes	leachate	yes	no	0 years	containment	minimisation recycling transfer	LAWDC	yes
none	passive, vented active, to flare or process	nil data	nil data	no	nil data	nil data	nil data	0 years	containment	landfill	not confirmed	nil data
public sewer	passive, through cover	occasional	leachate	yes	leachate	yes	yes	2-5 years	containment	incineration landfill	LAWDC	yes
recirculation on-site treatment	active, to flare or process	never	nil data	yes	leachate gas	yes	nil data	5-10 years	containment	recycling landfill	NAWDC	nil data
none	active, to flare or process	occasional	gas	no	nil data	nil data	nil data	2-5 years	containment	incineration landfill	LAWDC	yes
none nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
recirculation on-site treatment	active, to flare or process	never	nil data	no	nil data	nil data	nil data	5-10 years	containment	recycling landfill	NAWDC	nil data
none	active, to flare or process	nil data	nil data	yes	gas	yes	no	0 years	containment	recycling landfill	not confirmed	yes
tanker collection recirculation	active, to flare or process	nil data	nil data	no	nil data	nil data	nil data	more than ten	containment	recycling incineration landfill	not confirmed	nil data
recirculation	active, to flare or process	nil data	nil data	no	nil data	nil data	nil data	more than ten	containment	incineration landfill	not confirmed	nil data
public sewer	passive, through cover	nil data	nil data	yes	gas	yes	nil data	0 years	containment	recycling landfill incineration	LAWDC	yes
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data

Grid Re	Waste (	Licen	Waste T	Site He	Void Sp	Design Co	Basal Seal	Capping La	Use o		Base
NZ 207 339	Durham County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	ni
NZ 215 444	Durham County Council	no		*** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	ni
NZ 195 474	Durham County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	ni
NZ 205 342	Durham County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	ni
NZ 314 474	Durham County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	ni
NZ 307 506	Durham County Council	no	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	ni
NZ 328 367	Durham County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	ni
NZ 407 371	Durham County Council	no	inert	*** inc. H	less than one	landraise mineral void	none	mineral (eg clay)	no	nil data	ni
????	Durham County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	ni
SH 450 487	Dwyfor District Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	ni
TQ 771 084	East Sussex County Council	yes	inert municipal	**** inc. H	1-2	landraise cellular filling dilute and disperse	none	synthetic (plastic) cap	no	nil data	ni
TL 85 06	Essex County Council	no	inert municipal	*** inc. H	less than one	landraise	mineral (eg clay etc.)	mineral (eg clay)	no	nil data	ni
TL 948 224	Essex County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	ni
TL 85 06	Essex County Council	no	inert municipal	*** inc. H	less than one	landraise	mineral (eg clay etc.)	mineral (eg clay)	no	nil data	ni
TM 114 175	Essex County Council	no	inert municipal	*** inc. H	2-5	landraise dilute and disperse	mineral (eg clay etc.)	mineral (eg clay)	no	nil data	ni
TQ 745 855	Essex County Council	yes	co-disposal	**** inc. H	nil data	landraise	none	no cap(but soil-shale cover)	no	nil data	ni
TQ 92 89	Essex County Council	no	nil data	*** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
TQ 695 805	Essex County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
TQ 953 884	Essex County Council	no	inert municipal	*** inc. H	less than one	landraise other	mineral (eg clay etc.)	mineral (eg clay)	no	nil data	nil
TQ 555 806	Essex County Council	yes	municipal	*** inc. H	1-2	mineral void	mineral (eg clay etc.)	mineral (eg clay)	no	nil data	nil
TL 580 210	Essex County Council	nil data	nil data	*** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
TL 564 022	Essex County Council	yes	municipal	*** inc. H	2-5	mineral void	mineral (eg clay etc.)	mineral (eg clay)	no	nil data	nil
TL 565 023	Essex County Council	nil data	nil data	*** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
TL 725 285	Essex County Council	no	inert municipal	*** inc. H	1-2	mineral void dilute and disperse	mineral (eg clay etc.)	mineral (eg clay)	no	nil data	nil
TL 525 312	Essex County Council	no	nil data	*** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
TL 657 088	Essex County Council	nil data	nil data	*** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
TQ 614 819	Essex County Council	yes	inert municipal special	**** inc. H	nil data	mineral void	mineral (eg clay etc.)	mineral (eg clay)	no	nil data	nil
SO 933 268	Gloucestershire County Council	yes	inert municipal	**** inc. H	2-5	landraise containment cellular filling	mineral (eg clay etc.)	mineral (eg clay) reconditioned natural soil	no	nil data	nil
SO 810 180	Gloucestershire County Council	yes	inert municipal special alternative	**** inc. H	2-5	landraise containment	mineral (eg clay etc.)	mineral (eg clay) reconditioned natural soil	no	nil data	nil
SO 937 273	Gloucestershire County Council	yes	special co-disposal	**** inc. H	2-5	landraise containment	mineral (eg clay etc.)	mineral (eg clay)	in cap system	nil data	pul fuel

Leachat	Gas Manager	Syste	If Yes	Poll	If Yes	Land	Pond	Tippin	Landfill	Future Poll	Disposa	Disposa	
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	
consented outfall	passive, through cap passive, through cover	never	nil data	no	nil data	nil data	nil data	0 years	nil data	nil data	nil data	nil data	
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	
recirculation	passive, vented active, to flare or process	occasional	leachate	maybe	leachate	under review	under review	5-10 years	containment	minimisation recycling composting incineration digestion landfill transfer	NAWDC	yes way	miles,
none	passive, through cap passive, through cover	never	nil data	nil data	nil data	nil data	nil data	0 years	dilute and disperse	minimisation recycling composting incineration digestion landfill transfer	LAWDC	nil data	
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	
none	passive, through cap passive, through cover	never	nil data	nil data	nil data	nil data	nil data	0 years	dilute and disperse	minimisation recycling composting incineration digestion landfill transfer	LAWDC	nil data	
recirculation	active, to flare active, to flare or process	occasional	capping	yes	nil data	yes	yes	0 years	dilute and disperse	minimisation recycling composting incineration digestion landfill transfer	LAWDC	yes	
on-site treatment	passive, through cap passive, through cover	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	
none	passive, through cap nil data	nil data	nil data	no	nil data	nil data	nil data	0 years	dilute and disperse	minimisation recycling composting incineration digestion landfill transfer	LAWDC	yes	
recirculation	active, to turbine(energy)	never	nil data	no	nil data	nil data	yes	2-5 years	containment	landfill	not confirmed	no	
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	
recirculation	active, to turbine(energy)	never	nil data	no	nil data	nil data	yes	2-5 years	containment	landfill	not confirmed	no	
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	
none	active, to flare active, to flare or process	occasional	basal seal capping	yes	leachate	yes	yes	0 years	dilute and disperse	minimisation recycling composting incineration digestion landfill transfer	LAWDC	nil data	
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	
public sewer recirculation	active, to flare active, to turbine(energy) active, to flare or process	occasional	gas	nil data	nil data	yes	yes	nil data	nil data	nil data	nil data	nil data	
consented outfall on-site treatment	passive, vented	occasional	leachate	yes	leachate	yes	yes	more than ten	containment	recycling composting landfill	LAWDC	yes	
public sewer consented outfall on-site treatment	passive, vented	occasional	leachate	yes	leachate	yes	yes	more than ten	containment	recycling composting landfill	LAWDC	yes	
on-site treatment	passive, vented	never	nil data	no	nil data	nil data	yes	more than ten	containment	landfill	NAWDC	yes	

Grid Re	Waste (	Licen	Waste T	Site file	Void Sp	Design Co	Basal Seal	Capping La	Use o	If base	
SJ 292 416	Glyndwr District Council	yes	municipal	****inc.H	1-2	mineral void containment	composite (ie synthetic/mineral)	mineral (eg clay)	no	nil data	ı
SJ 125 597	Glyndwr District Council	yes	municipal	*** inc. H	less than one	landraise	none	no cap(but soil/shale cover)	no	nil data	r
SD 527 013	Greater Manchester WDA	nil data	nil data	*** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	(
SJ 947 874	Greater Manchester WDA	yes	inert	*** inc. H	less than one	dilute and disperse	none	mineral (eg clay)	no	nil data	r
SD 608 045	Greater Manchester WDA	yes	municipal	**** inc. H	2-5	mineral void dilute and disperse containment	none mineral (eg clay etc.)	mineral (eg clay)	in cap system	nil data	‹
SD 585 037	Greater Manchester WDA	yes	municipal	**** inc. H	nil data	containment	geomembrane composite (ie synthetic/mineral)	no cap(but soil shale cover)	in base system in cap system	colliery shale	c
SD 82 09	Greater Manchester WDA	yes	municipal special	**** inc. H	1-2	containment mineral void	geomembrane mineral (eg clay etc.)	mineral (eg clay)	no	nil data	r
SD 640 098	Greater Manchester WDA	no	municipal special	*** inc. H	nil data	landraise dilute and disperse	nime	mineral (eg clay)	no	nil data	n
SD 747 122	Greater Manchester WDA	yes	municipal	**** inc. H	nil data	dilute and disperse	none	mineral (eg clay)	no	nil data	n
SD 885 035	Greater Manchester WDA	yes	inert municipal special	**** inc. H	less than one	mineral void cellular filling containment	geomembrane mineral (eg clay etc.) bentonite enhanced soil composite (ie	synthetic (plastic) cap composite(synthetic mi neral)	no	nil data	n
SD 610 061	Greater Manchester WDA	yes	inert municipal	*** inc. H	1-2	mineral void cellular filling containment	geomembrane composite (ie synthetic/mineral) bentonite enhanced soil	composite(synthetic mi neral)	no	nil data	n
SD 85 05	Greater Manchester WDA *	yes	municipal	**** inc. H	less than one	mineral void containment cellular filling	mineral (eg clay etc) reconditioned natural soil reconditioned natural soil/clay	mineral (eg clay) reconditioned natural soil	no	nil data	n
SU 445 236	Hampshire County Council	no	nil data	*** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	n
SZ 579 989	Hampshire County Council	no	municipal	*** inc. H	nil data	dilute and disperse	none	no low permeability cap no cap(but soil shale cover)	no	nil data	n
SZ 208 986	Hampshire County Council	no	nil data	**** inc. H	nil data	nil data					
SU 637 049	Hampshire County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	ni
SU 552 095	Hampshire County Council	no	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	ni
SZ 312 928	Hampshire County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	ni
SU 341 182	Hampshire County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
SU 48 08	Hampshire County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
SU 512 052	Hampshire County Council	nil data	nil data	*** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
SU 425 047	Hampshire County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
SU 424 465	Hampshire County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
SU 425 473	Hampshire County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
SU 765 610	Hampshire County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
SU 123 067	Hampshire County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
SU 360 238	Hampshire County Council	nil data	nil data	*** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil (
SU 738 083	Hampshire County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil (

Leachat	Gas Manager	Syste	If Yes	Poll	If Yes	Failu	Pollu	Tippin	Landfill	Future Poll	Disposal	Disposal
tanker collection	active, to flare or process	nil data	nil data	nil data	nil data	nil data	nil data	5-10 years	containment	landfill	NAWDC	nil data
none	passive, through cap nil data	nil data	nil data	nil data	nil data	nil data	nil data	0 years	nil data	transfer	Joint Venture	yes no
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
none	passive, through cap passive, through cover	never	nil data	nil data	nil data	nil data	nil data	unknown	containment	minimisation recycling landfill	nil data	nil data
none	passive, vented	never	nil data	nil data	nil data	nil data	nil data	0 years	containment	minimisation recycling landfill	nil data	nil data
public sewer on-site treatment	passive, vented	never	nil data	nil data	nil data	nil data	nil data	0 years	containment	minimisation recycling landfill	nil data	nil data
public sewer tanker collection recirculation on-site treatment	passive, vented	never	nil data	nil data	nil data	nil data	nil data	1-2 years	containment	minimisation recycling landfill	nil data	nil data
none	passive, through cap passive, through cover	often	leachate	yes	leachate	yes	yes	0 years	containment	minimisation recycling landfill	nil data	nil data
public sewer	passive, through cap passive, through cover	occasional	leachate gas	yes	leachate	yes	yes	1-2 years	containment	minimisation recycling landfill	nil data	nil data
consented outfall	passive, vented active, to flare active, to turbine(energy)	occasional	leachate	yes	leachate	yes	yes	0 years	containment	minimisation recycling landfill	nil data	nil data
consented outfall	passive, vented	occasional	leachate	yes	leachate	yes	yes	5-10 years	containment	minimisation recycling landfill	nil data	nil data
public sewer consented outfall	passive, vented	never	nil data	nil data	nil data	nil data	nil data	0 years	containment	minimisation recycling landfill	nil data	yes
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
none	passive, through cap passive, vented passive, through cover	nil data	nil data	yes	nil data	nil data	under review	nil data	nil data	nil data	nil data	nil data
	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil datas	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data

Grid Re	Waste (	Licen	Waste T	Site Ne	Void Sp	Design Co	Basal Seal	Capping La	Use o	I Base I	
SU 404 444	Hampshire County Council	no	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil d
386000E 270200N	Hereford & Worcestershire C. C.	yes	inert municipal special co-disposal	**** inc. H	2-5	mineral void cellular filling containment	geomembrane mineral (eg clay etc.) reconditioned natural soil composite (ie	composite(synthetic mineral)	no	nil data	nil d
SO 485 386	Hereford & Worcestershire C. C.	no	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil d
SO 752 614	Hereford & Worcestershire C. C.	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil d
SO 795 730	Hereford & Worcestershire C. C.	yes	inert	**** inc. H	less than one	mineral void	none	no cap(but soil shale cover)	in cap system	nil data	alter
SO 795 730	Hereford & Worcestershire C. C.	yes	inert	**** inc. H	less than one	mineral void	none	no cap(but soil shale cover)	in cap system	nil data	alter
SO 976 486	Hereford & Worcestershire C. C.	yes	inert municipal	**** inc. H	2-5	landraise dilute and disperse containment	mineral (eg clay etc.)	mineral (eg clay)	no	nil data	nil c
SO 961 768	Hereford & Worcestershire C. C.	no	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil c
TL 305 145	Hertfordshire County Council	yes	inert municipal	**** inc. H	less than one 5-10	mineral void	none mineral (eg clay etc)	no cap(but soil shale cover) mineral (eg clay)	no	nil data	nil c
TL 345 157	Hertfordshire County Council	yes	inert municipal	*** inc. H	2-5	mineral void cellular filling containment	geomembrane mineral (eg clay etc)	synthetic (plastic) cap mineral (eg clay)	no	nil data	nil c
TL 340 154	Hertfordshire County Council	yes	inert municipal	**** inc. H	1-2	mineral void cellular filling containment	mineral (eg clay etc)	synthetic (plastic) cap mineral (eg clay)	no	nil data	nil c
TA 059 396	Humberside County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil c
TA 012 263	Humberside County Council	nil data	nil data	*** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil c
SE 939 650	Humberside County Council	no	nil data	*** inc. H	nil data	nil data					
TA 240 267	Humberside County Council	no	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil d
SE 727 348	Humberside County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil d
SE 912 202	Humberside County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil d
TA 238 129	Humberside County Council	no	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil d
TA 116 465	Humberside County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil d
TA 154 646	Humberside County Council	nil data	nil data	*** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil d
TA 20 14	Humberside County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil d
SE 993 065	Humberside County Council	no	nil data	**** inc. H	nil data	nil data					
SZ 534 884	Isle of Wight	nil data	nil data	*** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil d
SZ 534 884	Isle of Wight	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil d
SZ 535 879	Isle of Wight	no	nil data	*** inc. H	nil data	nil data					
ST 235 908	Islwyn Borough Council	no	municipal	**** inc. H	less than one	mineral void containment	mineral (eg clay etc.)	mineral (eg clay)	in base system	colliery shale	nil d

nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
tanker collection recirculation on-site treatment alternative	active, to flare or process	never	nil data	no	nil data	nil data	nil data	more than ten	containment co-disposal	minimisation recycling landfill	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
none	passive, vented	never	nil data	no	nil data	yes	yes	2-5 years	dilute and disperse	landfill	not confirmed	no
none	passive, vented	never	nil data	no	nil data	yes	yes	2-5 years	dilute and disperse	landfill	not confirmed	no
tanker collection	passive, through cap passive, vented passive, through cover	occasional	nil data	yes	leachate	yes	yes	2-5 years	containment	minimisation recycling composting landfill	LAWDC	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
none	active, to flare or process passive, vented	never	nil data	maybe	gas	nil data	nil data	1-2 years	containment	minimisation recycling composting incineration	NAWDC	yes ......miles. way
recirculation	passive, vented active, to flare or process	never	nil data	no	nil data	nil data	nil data	5-10 years	containment	minimisation recycling composting incineration	NAWDC	yes
recirculation	active, to flare or process	often	gas	yes	gas	yes	yes	2-5 years	containment	minimisation recycling composting incineration	NAWDC	yes .miles. way
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
public sewer	passive, vented	never	nil data	no	nil data	nil data	nil data	0 years	nil data	minimisation recycling transfer	nil data	nil data

TR 332 618	Kent County Council	no	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil da
TR 160 601	Kent County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil d:
SD 460 242	Lancashire County Council	yes	municipal	**** inc. H	less than one	landraise dilute and disperse	none	composite(synthetic/mineral)	no	nil data	nil d:
SD 330 455	Lancashire County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil d.
SD 450 280	Lancashire County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil d.
SD 455 625	Lancashire County Council	yes	municipal special co-disposal	**** inc. H	1-2	landraise	none	no low permeability cap no cap(but soil/shale cover)	no	other ...? alternative	nil d
SD 893 472	Lancashire County Council	no	nil data	*** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil d
SD 508 105	Lancashire County Council	nil data	nil data	*** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil d
SD 756 481	Lancashire County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil d
SD 728 404	Lancashire County Council	yes	municipal	**** inc. H	less than one	containment	mineral (eg clay etc.)	mineral (eg clay)	no	nil data	nil d
SD 52 22	Lancashire County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil d
SD 639 240	Lancashire County Council	yes	municipal co-disposal	*** inc. H	less than one	landraise cellular filling	none composite (ie synthetic/mineral)	mineral (eg clay)	in base system in cap system	china clay waste	chin. wast
SD 857 283	Lancashire County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil d
SD 864 333	Lancashire County Council	yes	municipal	**** inc. H	1-2	dilute and disperse containment	none composite (ie synthetic mineral)	no cap(but soil shale cover) mineral (eg clay)	in cap system	nil data	colli
SD 846 212	Lancashire County Council	yes	municipal	**** inc. H	less than one	mineral void dilute and disperse containment	none mineral (eg clay etc.)	no cap(but soil/shale cover) mineral (eg clay)	no	nil data	nil d
SD 487 771	Lancashire County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil d
SD 793 244	Lancashire County Council	no	nil data	*** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil d
nil data	Leicestershire County Council	yes	inert municipal	nil data	less than one	mineral void dilute and disperse containment	none mineral (eg clay etc.)	no cap(but soil shale cover) mineral (eg clay)	no	nil data	nil d
nil data	Leicestershire County Council	yes	inert municipal	nil data	2-5	mineral void containment	mineral (eg clay etc.)	mineral (eg clay)	no	nil data	nil d
nil data	Leicestershire County Council	yes	inert municipal	nil data	less than one	mineral void dilute and disperse	none	mineral (eg clay)	no	nil data	nil d
nil data	Leicestershire County Council	yes	inert municipal	nil data	2-5	mineral void other	none	mineral (eg clay)	no	nil data	nil d
nil data	Leicestershire County Council	yes	inert municipal	nil data	less than one	landraise mineral void dilute and disperse	none	mineral (eg clay)	no	nil data	nil d
nil data	Leicestershire County Council	yes	inert municipal	nil data	less than one	mineral void dilute and disperse containment	none mineral (eg clay etc.)	no cap(but soil/shale cover) mineral (eg clay)	no	nil data	nil d
nil data	Leicestershire County Council	yes	inert municipal	nil data	2-5	mineral void cellular filling containment	mineral (eg clay etc.)	mineral (eg clay)	no	nil data	nil d
SK 930 675	Lincolnshire County Council	no	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil d
SK 964 524	Lincolnshire County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil d
SK 989 243	Lincolnshire County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil d
TF 109 989	Lincolnshire County Council	no	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil d
SK 81 87	Lincolnshire County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil d

Leachat, Gas Manager Syste, ? Yes, ? On, ? Yes, Pand Pond, Tippin, Landfill, Future ? On, Disposa, Dispose

nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
public sewer recirculation on-site treatment	passive, through cap passive, vented passive, through cover	occasional	leachate	maybe	leachate	yes	yes	0 years	containment	landfill	LAWDC	yes
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
public sewer	active, to flare active, to turbine(energy) active, to flare or process	occasional	leachate	nil data	nil data	yes	yes	2-5 years	containment co-disposal	minimisation recycling composting landfill	LAWDC	yes
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
public sewer on-site treatment	active, to flare or process	occasional	leachate gas	no	nil data	nil data	yes	5-10 years	containment	composting landfill	LAWDC	yes
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
consented outfall recirculation on-site treatment	active, to turbine(energy)	occasional	nil data	yes	leachate	no	no	5-10 years	dilute and disperse containment	recycling landfill transfer	not confirmed	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
ublic sewer on-site treatment	active, to flare or process active, to turbine(energy)	occasional	leachate	yes	leachate	yes	no	2-5 years	containment	minimisation recycling composting landfill	LAWDC	yes
one public sewer	passive, through cap active, to flare or process passive, through cover	never	nil data	nil data	nil data	nil data	nil data	2-5 years	containment	minimisation recycling composting landfill	LAWDC	yes
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
one	passive, through cover	nil data	nil data	yes	leachate	no	yes	2-5 years	containment	minimisation recycling composting digestion landfill transfer	NAWDC	nil data
ecirculation	active, to flare or process active, to turbine(energy) alternative	occasional	leachate	no	nil data	yes	yes	2-5 years	nil data	minimisation recycling composting digestion landfill transfer	NAWDC	nil data
one	passive, vented	never	nil data	no	nil data	nil data	nil data	1-2 years	containment	minimisation recycling composting digestion landfill transfer	NAWDC	nil data
ublic sewer	active, to flare or process active, to turbine(energy)	occasional	gas	yes	gas	yes	under review	1-2 years	containment	minimisation recycling composting digestion landfill transfer	NAWDC	yes
one	active, to flare or process	occasional	gas	yes	gas	yes	yes	1-2 years	nil data	minimisation recycling composting digestion landfill transfer	NAWDC	nil data
one	alternative	nil data	nil data	yes	leachate	no	yes	2-5 years	containment	minimisation recycling composting digestion landfill transfer	NAWDC	nil data
anker collection ecirculation	passive, vented active, to flare or process active, to turbine(energy)	occasional	leachate	no	nil data	yes	nil data	5-10 years	containment	minimisation recycling composting digestion landfill transfer	NAWDC	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data

Grid Re	Waste I	Licen	Waste T	SiteFile	Void Sp	Design Co	Basal Seal	Capping La	use o	n base	I
SK 89 67	Lincolnshire County Council	no	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil d
??????	Lincolnshire County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil d
TF 338 842	Lincolnshire County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil c
TF 348 413	Lincolnshire County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil c
TF 342 336	Lincolnshire County Council	no	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil c
TF 393 762	Lincolnshire County Council	no	co-disposal	**** inc. H	less than one	dilute and disperse	none	mineral (eg clay)	nil data	nil data	nil c
TF 537 635	Lincolnshire County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil c
TQ 525 795	London Waste Regulation Authority	yes	municipal	**** inc. H	5-10	landraise containment	none other......................... ....?	no cap(but soil/shale cover)	no	nil data	nil c
SH 580 339	Meirionydd District Council	nil data	municipal	**** inc. H	nil data	dilute and disperse	none	no cap(but soil/shale cover)	nil data	nil data	nil c
SD 495 015	Merseyside Waste Disposal Authority	yes	inert municipal special	**** inc. H	less than one	landraise	none mineral (eg clay etc.)	synthetic (plastic) cap mineral (eg clay)	no	nil data	nil c
SJ 292 942	Merseyside Waste Disposal Authority	yes	inert municipal special	**** inc. H	nil data	landraise dilute and disperse	none	no cap(but soil/shale cover)	no	nil data	nil c
SJ 355 852	Merseyside Waste Disposal Authority	yes	inert municipal	*** inc. H	less than one	landraise	geomembrane	synthetic (plastic) cap	no	nil data	nil c
SD 527 013	Merseyside Waste Disposal Authority	yes	municipal	*** inc. H	less than one	mineral void containment	mineral (eg clay etc.)	no cap(but soil/shale cover)	no	nil data	nil c
SD 512 942	Merseyside Waste Disposal Authority	no	inert municipal special	**** inc. H	2-5	cellular filling dilute and disperse containment	none mineral (eg clay etc)	no cap(but soil shale cover) mineral (eg clay)	no	nil data	nil c
SO 084 077	Merthyr Tydfil Borough Council	yes	co-disposal	nil data	more than ten	mineral void containment	geomembrane	synthetic (plastic) cap	in base system in cap system	colliery shale	colli
SN 971 824	Montgomery District Council	no	inert municipal	nil data	less than one	mineral void containment	mineral (eg clay etc.)	nil data	no	nil data	nil c
SS 734 956	Neath Borough Council	yes	municipal	*** inc. H	2-5	landraise cellular filling containment	none geomembrane mineral (eg clay etc) composite (ie synthetic mineral)	synthetic (plastic) cap mineral (eg clay)	no	nil data	nil d
ST 305 853	Newport Borough Council	yes	inert municipal	**** inc. H	2-5	landraise cellular filling dilute and disperse containment	mineral (eg clay etc.)	mineral (eg clay) composite(synthetic mineral)	no	nil data	nil c
TL 743 922	Norfolk County Council	no	nil data	*** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil c
TM 012 902	Norfolk County Council	no	nil data	*** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil c
TF 315 000	Norfolk County Council	nil data	nil data	*** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil c
TG 085 355	Norfolk County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
TF 956 188	Norfolk County Council	nil data	nil data	*** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
TG 245 213	Norfolk County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
TG 150 162	Norfolk County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
TG 155 110	Norfolk County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
TM 467 927	Norfolk County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
TF 675 149	Norfolk County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil

Leachat	Gas Manager	Syste	If Yes	Poll	If Yes	Land	Pond	Tippin	Landfill	Future Poll	Disposa	Dispose
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
none	passive, vented	never	nil data	no	nil data	nil data	nil data	0 years	nil data	minimisation recycling composting landfill	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
public sewer consented outfall	passive, through cover active, to flare or process	occasional	leachate gas	maybe	nil data	under review	under review	1-2 years	nil data	minimisation recycling	NAWDC	yes
none	passive, vented	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	not confirmed	nil data
public sewer tanker collection	active, to flare or process	occasional	nil data	nil data	leachate gas	nil data	nil data	2-5 years	containment	nil data	NAWDC	yes
none	active, to turbine(energy)	never	nil data	yes	leachate	no	no	1-2 years	containment	nil data	LAWDC	yes
consented outfall	active, to flare or process	nil data	nil data	nil data	nil data	nil data	nil data	5-10 years	containment	nil data	NAWDC	yes
public sewer consented outfall on-site treatment	active, to turbine(energy)	occasional	gas	no	nil data	yes	yes	2-5 years	containment	nil data	LAWDC	yes
none public sewer	active, to turbine(energy)	nil data	nil data	nil data	nil data	nil data	nil data	0 years	dilute and disperse containment	nil data	NAWDC LAWDC	yes
public sewer recirculation	passive, vented active, to flare or process	occasional	gas	yes	gas	yes	yes	more than ten	containment	recycling landfill	NAWDC	nil data
public sewer on-site treatment	other......................? alternative	nil data	nil data	nil data	nil data	nil data	nil data	5-10 years	containment	minimisation recycling composting landfill	not confirmed	yes
consented outfall	passive, vented	occasional	leachate	yes	leachate	yes	yes	more than ten	containment	minimisation recycling landfill	LAWDC	yes
consented outfall on-site treatment	passive, vented active, to flare or process	never	nil data	no	nil data	yes	yes	more than ten	dilute and disperse	recycling composting landfill	LAWDC not confirmed	yes
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data

Grid Re	Waste	Licen	Waste T	Site life	Void Sp	Design Co	Basal Seal	Capping La	Use o	If base	
TF 790 358	Norfolk County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil d
TF 790 358	Norfolk County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil d
SE 496 293	North Yorkshire County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
SE 512 144	North Yorkshire County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
SE 530 517	North Yorkshire County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
SE 523 664	North Yorkshire County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
SE 491 295	North Yorkshire County Council	no	nil data	*** inc. H	nil data	nil data					
SD 825 667	North Yorkshire County Council	no	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
TA 033 824	North Yorkshire County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
SE 407 597	North Yorkshire County Council	yes	co-disposal	**** inc. H	2-5	mineral void containment	composite (ie synthetic mineral)	synthetic (plastic) cap mineral (eg clay)	in base system	overburden waste	nil
SE 280 790	North Yorkshire County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
SE 655 288	North Yorkshire County Council	yes	inert	*** inc. H	more than ten	landraise containment	mineral (eg clay etc)	reconditioned natural soil	no	nil data	nil
SE 626 402	North Yorkshire County Council	yes	inert municipal co-disposal	**** inc. H	2-5	landraise mineral void cellular filling containment	bentonite enhanced soil composite (ie synthetic mineral) mineral (eg clay etc)	mineral (eg clay)	no	nil data	nil
SE 649 861	North Yorkshire County Council	no	nil data	*** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
SE 795 632	North Yorkshire County Council	no	nil data	*** inc. H	nil data	nil data					
SE020 532	North Yorkshire County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
NZ 807 136	North Yorkshire County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
SE 888 749	North Yorkshire County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
SE 833 835	North Yorkshire County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
SP 564 695	Northamptonshire County Council	yes	inert municipal	**** inc. H	nil data	cellular filling containment	mineral (eg clay etc.)	mineral (eg clay)	nil data	nil data	nil
SP 664 772	Northamptonshire County Council	yes	co-disposal	**** inc. H	nil data	mineral void cellular filling dilute and disperse containment	composite (ie synthetic/mineral)	bentonite enhanced soil composite(synthetic/mineral)	in cap system	nil data	grav wast
SP 643 781	Northamptonshire County Council	yes	co-disposal	**** inc. H	nil data	mineral void cellular filling containment	mineral (eg clay etc.)	mineral (eg clay)	no	nil data	nil
SP 914 701	Northamptonshire County Council	yes	co-disposal	**** inc. H	nil data	cellular filling dilute and disperse containment	mineral (eg clay etc.)	mineral (eg clay)	nil data	nil data	nil d
SP 900 910	Northamptonshire County Council	yes	co-disposal	**** inc. H	nil data	dilute and disperse	none	no cap(but soil/shale cover)	no	nil data	nil d
SP 916 884	Northamptonshire County Council	yes	inert municipal	*** inc. H	2-5	mineral void cellular filling containment	mineral (eg clay etc.)	mineral (eg clay)	no	nil data	nil d

Leachat	Gas Manager Syste	If Yes	Poll	If Yes	Pand	Pond	Tippin	Landfill	Future	Poll	Disposa	Disposa
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
on-site treatment	passive, vented	never	nil data	no	nil data	nil data	nil data	more than ten	containment co-disposal	minimisation recycling incineration landfill	NAWDC	yes
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
consented outfall	nil data	never	nil data	no	nil data	nil data	yes	more than ten	containment	minimisation landfill	nil data	nil data
tanker collection recirculation on-site treatment	passive, vented active, to flare or process active, to turbine(energy)	never	nil data	no	nil data	nil data	yes	more than ten	containment co-disposal	minimisation recycling landfill	Joint Venture	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	passive, vented	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	active, to flare or process active, to turbine(energy)	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	.........miles,1-w nil data
nil data	passive, vented active, to flare or process	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
recirculation	passive, vented	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data		nil data	nil data	nil data	nil data	nil data	nil data
recirculation	passive, vented	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data

Grid Re	Waste	Licen	Waste T	Site	Void Sp	Design Co	Basal Seal	Capping La	Use o	Base	
SP 935 766	Northamptonshire County Council	yes	inert municipal	**** inc. H	nil data	cellular filling dilute and disperse	none	mineral (eg clay)	nil data	nil data	nil d
SP 763 555	Northamptonshire County Council	yes	co-disposal	**** inc. H	1-2	cellular filling containment	mineral (eg clay etc.)	mineral (eg clay)	nil data	nil data	nil d
SP 755 716	Northamptonshire County Council	yes	inert municipal	**** inc. H	nil data	mineral void dilute and disperse containment	none mineral (eg clay etc.)	mineral (eg clay)	nil data	nil data	nil c
SP 880 914	Northamptonshire County Council	yes	inert	**** inc. H	nil data	mineral void cellular filling dilute and disperse	none	mineral (eg clay)	nil data	nil data	nil c
SP 848 836	Northamptonshire County Council	yes	co-disposal	**** inc. H	nil data	dilute and disperse	none	nil data	nil data	nil data	nil
NY 902 857	Northumberland County Council	no	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
NZ 239 951	Northumberland County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
NY 892 688	Northumberland County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
NZ 258 896	Northumberland County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
NU 012 468	Northumberland County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
NU 153 076	Northumberland County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
NZ 298 742	Northumberland County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
SK 597 473	Nottinghamshire County Council	yes	inert municipal special	**** inc. H	1-2	mineral void containment	mineral (eg clay etc.)	mineral (eg clay)	no	nil data	nil
SK 658 606	Nottinghamshire County Council	no	inert municipal special	**** inc. H	less than one	mineral void	mineral (eg clay etc.)	mineral (eg clay)	no	nil data	nil
SK 658 606	Nottinghamshire County Council	yes	inert municipal special	**** inc. H	less than one	mineral void containment	mineral (eg clay etc.)	mineral (eg clay)	no	nil data	nil
SK 474 582	Nottinghamshire County Council	yes	municipal	**** inc. H	nil data	landraise mineral void containment	mineral (eg clay etc.)	mineral (eg clay)	no	nil data	nil
SK 589 499	Nottinghamshire County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
SK 590 470	Nottinghamshire County Council	no	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
SK 743 349	Nottinghamshire County Council	no	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
SK 743 349	Nottinghamshire County Council	yes	inert municipal special	**** inc. H	less than one	landraise containment	mineral (eg clay etc.)	mineral (eg clay)	no	nil data	nil
SK 796 482	Nottinghamshire County Council	no	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
SK 726 578	Nottinghamshire County Council	no	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
SK 680 865	Nottinghamshire County Council	yes	inert municipal special	**** inc. H	2-5	landraise	composite (ie synthetic/mineral)	mineral (eg clay)	no	nil data	nil
SK 680 865	Nottinghamshire County Council	yes	municipal	**** inc. H	nil data	landraise	composite (ie synthetic/mineral)	reconditioned natural soil	no	nil data	nil
SK 726 578	Nottinghamshire County Council	yes	inert municipal special co-disposal	**** inc. H	nil data	landraise cellular filling containment	composite (ie synthetic/mineral)	composite(synthetic/mineral)	no	nil data	nil

Leachat	Gas Manager	Syste	If Yes	Poll	If Yes	Pand	Pond	Tippin	Landfill	Future	Poll	Disposa	Disposa
nil data	passive, vented	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data		nil data	nil data
recirculation on-site treatment	passive, vented	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data		nil data	nil data
nil data	passive, vented	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data		nil data	nil data
on-site treatment	passive, through cover	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data		nil data	nil data
nil data	passive, vented	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data		nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data		nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data		nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data		nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data		nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data		nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data		nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data		nil data	nil data
tanker collection	active, to flare or process	never	nil data	yes	gas	yes	yes	more than ten	containment	recycling composting incineration landfill		LAWDC	yes
tanker collection	active, to turbine(energy)	never	nil data	yes	gas	yes	yes	5-10 years	containment	recycling composting incineration landfill		LAWDC	yes
tanker collection	active, to turbine(energy)	never	nil data	yes	gas	yes	yes	5-10 years	containment	recycling composting incineration landfill		LAWDC	yes
on-site treatment alternative	active, to turbine(energy)	occasional	nil data	yes	gas	yes	yes	5-10 years	containment	recycling composting incineration landfill		LAWDC	yes
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data		nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data		nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data		nil data	nil data
tanker collection	active, to flare or process	never	nil data	no	nil data	nil data	nil data	5-10 years	containment	recycling composting incineration landfill		LAWDC	yes
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data		nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data		nil data	nil data
tanker collection	active, to turbine(energy)	never	nil data	no	nil data	nil data	nil data	more than ten	containment	recycling composting incineration landfill		LAWDC	yes
nil data	nil data	nil datanil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data		nil data	nil data
on-site treatment	active, to flare or process	occasional	nil data	no	nil data	yes	yes	2-5 years	nil data	recycling composting incineration landfill		LAWDC	yes

Grid Re	Waste t	Licer	Waste T	Site he	Void Sp	Design ce	Basal Seal	Capping	La	Use o	Base
SS 846 805	Ogwr Borough Council	yes	inert municipal special		1-2	mineral void cellular filling dilute and disperse	none alternative	mineral (eg clay)	no	nil data	nil
SS 852 788	Ogwr Borough Council	yes	inert municipal special	**** inc. H	1-2	mineral void cellular filling dilute and disperse	none	composite(synthetic/mineral) not confirmed	no	nil data	nil
SU 520 935	Oxfordshire County Council	no	inert municipal	**** inc. H	1-2	mineral void cellular filling	mineral (eg clay etc.)	no cap(but soil shale cover)	in cap system	nil data	pulv fuel
SU 491 949	Oxfordshire County Council	yes	inert	nil data	2-5	mineral void containment	mineral (eg clay etc.)	mineral (eg clay)	no	nil data	nil
SU 50 92	Oxfordshire County Council	yes	nil data	*** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
SU 509 929	Oxfordshire County Council	yes	inert municipal	*** inc. H	1-2	landraise mineral void containment	mineral (eg clay etc)	mineral (eg clay)	no	nil data	nil
SP 383 434	Oxfordshire County Council	no	inert municipal special	**** inc. H	2-5	landraise mineral void containment	mineral (eg clay etc)	mineral (eg clay)	no	nil data	nil
SP 383 434	Oxfordshire County Council	yes	inert municipal	**** inc. H	1-2	landraise mineral void containment	mineral (eg clay etc)	synthetic (plastic) cap mineral (eg clay)	no	nil data	nil
SP 383 434	Oxfordshire County Council	yes	inert municipal	**** inc. H	less than one	mineral void dilute and disperse	none	no cap(but soil shale cover)	no	nil data	nil
SP 343 213	Oxfordshire County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
SP 343 213	Oxfordshire County Council	yes	inert municipal	**** inc. H	less than one	mineral void containment	mineral (eg clay etc)	mineral (eg clay)	no	nil data	nil
SP 343 213	Oxfordshire County Council	yes	nil data	*** inc. H	nil data	nil data	mineral (eg clay etc)	mineral (eg clay)	no	nil data	nil
SP 415 058	Oxfordshire County Council	yes	inert municipal special	**** inc. H	5-10	landraise mineral void containment	mineral (eg clay etc)	mineral (eg clay)	no	nil data	nil
SU 642 892	Oxfordshire County Council	no	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
SU 640 892	Oxfordshire County Council	yes	inert municipal	**** inc. H	2-5	landraise mineral void containment	mineral (eg clay etc)	mineral (eg clay)	no	nil data	nil
SU 325 942	Oxfordshire County Council	no	inert municipal special	**** inc. H	1-2	landraise mineral void dilute and disperse	none	no cap(but soil shale cover)	in cap system	nil data	other alte
SP 543 261	Oxfordshire County Council	yes	inert municipal special	**** inc. H	1-2	landraise mineral void containment	mineral (eg clay etc)	synthetic (plastic) cap mineral (eg clay)	no	nil data	nil
SP 562 192	Oxfordshire County Council	yes	inert commercial	*** inc. H	less than one	mineral void containment	mineral (eg clay etc)	mineral (eg clay)	no	nil data	nil
SU 646 906	Oxfordshire County Council	yes	inert municipal special co-disposal	**** inc. H	1-2	landraise mineral void containment	mineral (eg clay etc)	mineral (eg clay)	no	nil data	nil
SM 968 218	Preseli Pembrokeshire District Council	yes	inert municipal special	**** inc. H	nil data	landraise cellular filling	mineral (eg clay) none composite (ie synthetic mineral)	clay mineral (eg clay) composite(synthetic mineral)	no	nil data	nil
SO 218 436	Radnor District Council	no	municipal	nil data	less than one	landraise	none	mineral (eg clay)	no	nil data	nil
SS 986 940	Rhondda Borough Council	yes	inert municipal	*** inc.H	2-5	containment landraise	HDPE geomembrane	HDPE synthetic (plastic) cap mineral (eg clay)	in base in base system	colliery shale	nil
ST 155 897	Rhymney Valley District Council	yes	municipal		less than one	cellular filling dilute and disperse	none	mineral (eg clay)	no	nil data	nil
SO 431 801	Shropshire County Council	yes	inert municipal	**** inc. H	less than one	landraise dilute and disperse	none	mineral (eg clay)	no	nil data	nil
SO 761 922	Shropshire County Council	yes	inert municipal	**** inc. H	less than one	landraise cellular filling containment	mineral (eg clay etc.)	mineral (eg clay)	no	nil data	nil
SJ 514 083	Shropshire County Council	yes	inert municipal co-disposal	**** inc. H	less than one	landraise cellular filling containment	mineral (eg clay etc.)	mineral (eg clay)	no	nil data	nil
SJ 423 325	Shropshire County Council	yes	inert municipal	**** inc. H	1-2	mineral void cellular filling containment	mineral (eg clay etc.)	mineral (eg clay)	no	nil data	nil

Leachat	Gas Manager	Syste	If Yes	Fun	If Yes	Fand	Fund	Tippin	Landfill	Future Fun	Disposa	Dispos
none	active, to flare or process alternative	occasional	leachate gas	yes	leachate gas	yes no	yes no	1-2 years	containment co-disposal	minimisation recycling transfer	NAWDC	no
none	passive, vented active, to flare or process active, to turbine(energy)	nil data	nil data	yes	leachate	no	under review	2-5 years	containment co-disposal	nil data	nil data	no
none	nil data	nil data	nil data	yes	leachate gas	yes	no	0 years	containment	landfill	NAWDC	nil data
tanker collection	passive, vented	often	capping leachate	no	nil data	yes	yes	2-5 years	containment	landfill	NAWDC	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	active, to flare or process	nil data	nil data	yes	gas	yes	yes	unknown	containment	landfill	NAWDC	nil data
tanker collection	passive, vented	never	nil data	yes	leachate	yes	yes	more than ten over 10	containment	landfill	NAWDC	nil data
tanker collection	passive, vented active, to flare or process	never	nil data	no	nil data	nil data	nil data	more than ten	containment	minimisation recycling composting landfill	NAWDC	nil data
tanker collection	passive, through cover	never	nil data	yes	leachate	yes	yes	0 years	containment	recycling composting landfill	NAWDC	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
tanker collection	passive, vented	occasional	leachate	no	nil data	nil data	yes	1-2 years	containment	recycling composting landfill	NAWDC	nil data
tanker collection	passive, vented	occasional	basal seal	yes	gas	yes	yes	1-2 years	containment	landfill	NAWDC	nil data
nil data	active, to flare or process	never	nil data	no	nil data	nil data	nil data	more than ten	containment	landfill	NAWDC	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
tanker collection	passive, vented	nil data	nil data	yes	gas	yes	yes	2-5 years	containment	recycling composting landfill	NAWDC	nil data
none	nil data	nil data	nil data	yes	leachate gas	nil data	nil data	0 years	containment	minimisation recycling composting landfill	NAWDC	nil data
tanker collection	active, to flare or process	nil data	nil data	yes	leachate gas	yes	yes	more than ten	containment	landfill	NAWDC	nil data
tanker collection	passive, vented	nil data	nil data	no	nil data	nil data	nil data	1-2 years	containment	landfill	NAWDC	nil data
tanker collection	passive, vented	nil data	nil data	no	nil data	nil data	nil data	5-10 years	containment	incineration landfill transfer	NAWDC	nil data
disposal tanker collection	passive, vented	occasional	leachate	yes	leachate	yes	no	2-5 years	containment	landfill	Undecided NAWDC	? yes
none	passive, vented	never	nil data	no	nil data	nil data	nil data	0 years	containment	recycling landfill	LAWDC	no
disposal public sewer	passive, vented	occasional	leachate	maybe	leachate	nil data	nil data	more than ten	containment	recycling landfill	LAWDC	yes
public sewer consented outfall	passive, vented	occasional	nil data	yes	leachate	yes	no	5-10 years	containment	minimisation recycling landfill	Joint Venture	nil data
tanker collection	passive, vented	occasional	gas leachate	yes	leachate gas	no	no	1-2 years	containment	landfill	LAWDC Joint Venture	yes
tanker collection	passive, vented	occasional	gas	yes	gas	yes	yes	2-5 years	containment	landfill	Joint Venture	yes
tanker collection	passive, vented active, to flare or process	occasional	gas	yes	gas	yes	no	2-5 years	containment	landfill	Joint Venture	yes
tanker collection	passive, vented	never	nil data	nil data	nil data	nil data	nil data	more than ten	containment	landfill	not confirmed	yes

Grid Re	Waste (	Licen	Waste T	Site ne	Void Sp	Design Ce	Basal Seal	Capping La	Use o	f Base	
SJ 572 337	Shropshire County Council	yes	inert municipal	**** inc. H	less than one	landraise cellular filling containment	mineral (eg clay etc.)	mineral (eg clay)	no	nil data	nil
SJ 725 121	Shropshire County Council	yes	inert municipal co-disposal	**** inc. H	1-2	landraise cellular filling containment	mineral (eg clay etc.)	mineral (eg clay)	in base system in cap system	colliery shale	coll
SJ 666 062	Shropshire County Council	yes	inert municipal co-disposal	**** inc. H	1-2	mineral void cellular filling containment	mineral (eg clay etc.)	mineral (eg clay)	no	nil data	nil
ST 312 427	Somerset County Council	yes	municipal	**** inc. H	nil data	landraise cellular filling containment	mineral (eg clay etc.)	synthetic (plastic) cap	no	nil data	nil
ST 312 429	Somerset County Council	yes	municipal	*** inc. H	nil data	landraise cellular filling containment	mineral (eg clay etc)	synthetic (plastic) cap	no	nil data	nil
ST 096 421	Somerset County Council	yes	municipal	**** inc. H	nil data	landraise cellular filling containment	geomembrane other ....?	mineral (eg clay)	no	nil data	nil
ST 152 217	Somerset County Council	yes	municipal	**** inc. H	nil data	mineral void cellular filling containment	mineral (eg clay etc)	mineral (eg clay)	no	nil data	nil
ST 614 311	Somerset County Council	yes	municipal special	**** inc. H	nil data	landraise cellular filling containment	mineral (eg clay etc) reconditioned natural soil clay	mineral (eg clay) reconditioned natural soil	no	nil data	nil
ST 494 147	Somerset County Council	yes	municipal	**** inc. H	nil data	landraise cellular filling dilute and disperse	none	mineral (eg clay)	no	nil data	nil
SK 395 924	South Yorkshire County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
SK 347 898	South Yorkshire County Council	no	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
SK 425 945	South Yorkshire County Council	no	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
SK 427 839	South Yorkshire County Council	no	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
SK 52 97	South Yorkshire County Council	no	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
SK 305 916	South Yorkshire County Council	nil data	nil data	*** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
SK 445 843	South Yorkshire County Council	no	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
SK 512 927	South Yorkshire County Council	no	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
?????????	South Yorkshire County Council	no	nil data	*** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
SE 488 003	South Yorkshire County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
SE 521 054	South Yorkshire County Council	no	nil data	*** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
SE 411 031	South Yorkshire County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
SE 433 013	South Yorkshire County Council	no	nil data	**** inc. H	nil data	nil data					
SE 657 107	South Yorkshire County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
SK 346 899	South Yorkshire County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
SE 538 009	South Yorkshire County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil
SE 592 094	South Yorkshire County Council	nil data	nil data	*** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil

Leachat	Gas Manager	Syste	If Yes	Pon	If Yes	Pand	Pond	Tippin	Landfill	Future	Pon	Disposa	Disposa
tanker collection	passive, vented	never	nil data	no	nil data	nil data	nil data	2-5 years	containment	landfill		Joint Venture	yes
tanker collection recirculation	passive, vented	never	nil data	no	nil data	nil data	nil data	5-10 years	containment	landfill		Joint Venture	yes
tanker collection recirculation	passive, vented	never	nil data	nil data	nil data	nil data	nil data	1-2 years	containment co-disposal	landfill		NAWDC	yes
consented outfall on-site treatment	active, to flare or process	occasional	leachate	no	nil data	yes	yes	nil data	containment	nil data		LAWDC	yes
consented outfall on-site treatment	active, to flare or process	occasional	leachate	no	nil data	yes	yes	nil data	containment	nil data		LAWDC	yes
on-site treatment	passive, vented active, to flare or process	occasional	leachate	no	nil data	yes	yes	nil data	containment	nil data		LAWDC	yes
public sewer	passive, vented active, to flare or process	occasional	gas	nil data	nil data	yes	yes	unknown	containment	landfill		LAWDC	yes
consented outfall recirculation on-site treatment	active, to flare or process	occasional	leachate	yes	leachate	yes	yes	nil data	containment	nil data		LAWDC	yes
consented outfall recirculation	passive, vented active, to flare or process	occasional	nil data	yes	gas	yes	yes	0 years	containment	nil data		LAWDC	yes
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data		nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data		nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data		nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data		nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data		nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data		nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data		nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data		nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data		nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data		nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data		nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data		nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data		nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data		nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data		nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data		nil data	nil data

Grid Re	Waste I	Licei	Waste T	Site re	Void Sp	Design Co	Basal Seal	Capping La	Use o	n Base n	
SK 142 302	Staffordshire County Council	yes	municipal	**** inc. H	less than one	landraise cellular filling containment	mineral (eg clay etc.)	bentonite enhanced soil	no	nil data	nil c
SK 142 302	Staffordshire County Council	no	nil data	*** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil c
SJ 866 494	Staffordshire County Council	no	nil data	*** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil c
SJ 883 549	Staffordshire County Council	no	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil c
SJ 847 505	Staffordshire County Council	no	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil c
SJ 987 573	Staffordshire County Council	no	nil data	*** inc. H	nil data	nil data					
SJ 844 343	Staffordshire County Council	nil data	nil data	*** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil c
SJ 891 503	Staffordshire County Council	no	nil data	*** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil c
SK 01 05	Staffordshire County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil c
SK 034 372	Staffordshire County Council	nil data	nil data	*** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil c
SJ 995 090	Staffordshire County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil c
SJ 967 051	Staffordshire County Council	no	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil c
SJ 995 090	Staffordshire County Council	yes	inert municipal	**** inc. H	more than ten	landraise mineral void containment	mineral (eg clay etc) bentonite enhanced soil	mineral (eg clay)	no	nil data	nil c
SO 844 956	Staffordshire County Council	yes	inert residue burnt residue	*** inc. H	less than one	mineral void dilute and disperse	none	not confirmed alternative	nil data	nil data	nil c
SY 985 573	Staffordshire County Council	no	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil c
SK 844 343	Staffordshire County Council	no	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil d
SO 899 911	Staffordshire County Council	yes	inert municipal special co-disposal	**** inc. H	2-5	landraise mineral void cellular filling containment	mineral (eg clay etc)	mineral (eg clay)	no	nil data	nil d
TL 795 695	Suffolk County Council	yes	municipal	**** inc. H	less than one	containment	composite (ie synthetic mineral) bentonite enhanced soil	synthetic (plastic) cap	no	nil data	nil d
TL 997 625	Suffolk County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil d
TM 112 500	Suffolk County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil d
TM 524 883	Suffolk County Council	nil data	nil data	*** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil d
TM 467 777	Suffolk County Council	yes	municipal	**** inc. H	less than one	containment	composite (ie synthetic mineral) bentonite enhanced soil	synthetic (plastic) cap	no	nil data	nil d
TM 247 813	Suffolk County Council	nil data	nil data	*** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil d.
TQ 207 516	Surrey County Council	yes	inert municipal	*** inc. H	less than one	mineral void dilute and disperse	none	mineral (eg clay)	no	nil data	nil d.
TQ 393 463	Surrey County Council	yes	inert municipal	*** inc. H	less than one	mineral void containment	mineral (eg clay etc.)	mineral (eg clay)	no	nil data	nil d
SU 88 48	Surrey County Council	yes	inert municipal	*** inc. H	less than one	mineral void cellular filling dilute and disperse	none	synthetic (plastic) cap	in base system	other ...? alternative	nil d

Leachat	Gas Managei Syste		If Yes	Pon	If Yes	Land	Pond	Tippin	Landfill	Future Pon	Disposa	Disposa
none	passive, through cap passive, through cover	never	nil data	no	nil data	nil data	nil data	2-5 years	containment	recycling composting landfill transfer	LAWDC	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
consented outfall on-site treatment	active, to turbine(energy)	occasional	leachate	no	nil data	nil data	yes	more than ten	containment	recycling composting landfill	LAWDC	yes
none	passive, vented	nil data	nil data	maybe	nil data	nil data	under review	5-10 years	containment	incineration landfill	not confirmed	yes
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
consented outfall other................ ....? alternative	active, to flare active, to flare or process	occasional	gas	yes	gas	yes	no	nil data	containment co-disposal	recycling landfill	NAWDC	nil data
recirculation	active, to flare or process	never	nil data	no	nil data	nil data	nil data	more than ten	containment	landfill	LAWDC	yes
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
recirculation	active, to flare or process	never	nil data	no	nil data	nil data	nil data	more than ten	containment	landfill	LAWDC	yes
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
none	passive, vented	never	nil data	no	nil data	nil data	yes	2-5 years	containment	minimisation recycling incineration	NAWDC	yes
tanker collection	active, to flare or process	occasional	nil data	yes	gas	yes	yes	0 years	containment	minimisation recycling incineration	LAWDC	yes
none	active, to flare or process	often	nil data	yes	gas	yes	yes	1-2 years	containment	minimisation recycling incineration	NAWDC	no

Grid Re	Waste (	Licen	Waste T	Site He	Void Sp	Design Cc	Basal Seal	Capping La	Use o	I Base	n C
TQ 130 136	West Sussex County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil dat
TQ 173 346	West Sussex County Council	nil data	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil dat
SE 117 113	West Yorkshire JWMD	no	municipal	**** inc. H	nil data	mineral void	nil data	mineral (eg clay)	nil data	nil data	nil dat
SD 952 240	West Yorkshire JWMD	yes	municipal	**** inc. H	nil data	landraise	nil data	mineral (eg clay)	nil data	nil data	nil dat
SE 050 375	West Yorkshire JWMD	yes	inert municipal special co-disposal	**** inc. H	nil data	landraise cellular filling containment	mineral (eg clay etc)	mineral (eg clay)	nil data	nil data	nil dat
SE 106 200	West Yorkshire JWMD	yes	municipal	*** inc. H	nil data	mineral void cellular filling containment	mineral (eg clay etc)	mineral (eg clay)	no	nil data	nil dat
SE 103 197	West Yorkshire JWMD	yes	inert special	**** inc. H	nil data	mineral void other	none	mineral (eg clay)	no	nil data	nil dat
SE 12 12	West Yorkshire JWMD	no	inert municipal special co-disposal	**** inc. H	nil data	mineral void cellular filling containment	mineral (eg clay etc)	mineral (eg clay)	no	nil data	nil dat
SE 259 256	West Yorkshire JWMD	yes	special co-disposal municipal	**** inc. H	nil data	mineral void containment	composite (ie synthetic mineral)	composite(synthetic mineral)	no	nil data	nil da
SE 242 274	West Yorkshire JWMD	no	nil data	**** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil da
SE 229 209	West Yorkshire JWMD	yes	inert municipal special co-disposal	**** inc. H	nil data	containment	mineral (eg clay etc)	mineral (eg clay)	nil data	nil data	nil da
SE 265 247	West Yorkshire JWMD	yes	municipal special co-disposal	**** inc. H	nil data	mineral void containment	mineral (eg clay etc)	mineral (eg clay)	no	nil data	nil da
[illegible]	West Yorkshire JWMD	yes	municipal special co-disposal	*** inc. H	nil data	mineral void containment	composite (ie synthetic mineral)	mineral (eg clay)	no	nil data	nil da
SE 393 247	West Yorkshire JWMD	no	municipal	**** inc. H	nil data	mineral void	nil data	nil data	nil data	nil data	nil da
SE 370 310	West Yorkshire JWMD	yes	municipal special co-disposal	**** inc. H	nil data	mineral void containment	mineral (eg clay etc.)	nil data	nil data	nil data	nil da
SE 218 087	West Yorkshire JWMD	yes	municipal	*** inc. H	less than one	mineral void	mineral (eg clay etc)	mineral (eg clay)	no	nil data	nil d.
SE 160 280	West Yorkshire JWMD	yes	inert municipal special co-disposal	**** inc. H	nil data	dilute and disperse	nil data	reconditioned natural soil	nil data	nil data	nil d.
SE 151 182	West Yorkshire JWMD	yes	inert municipal	**** inc. H	less than one	dilute and disperse	none	not confirmed	no	nil data	nil d.
SE 125 225	West Yorkshire JWMD	yes	municipal	**** inc. H	nil data	mineral void containment dilute and disperse	mineral (eg clay etc.) none	mineral (eg clay)	no	nil data	nil d.
SE 165 278	West Yorkshire JWMD	nil data	inert municipal special co-disposal	**** inc. H	nil data	dilute and disperse	nil data	reconditioned natural soil	nil data	nil data	nil d.
SE 215 085	West Yorkshire JWMD	no	municipal	*** inc. H	nil data	mineral void	mineral (eg clay etc.)	mineral (eg clay)	no	nil data	nil d.
SE 202 143	West Yorkshire JWMD	yes	municipal	*** inc. H	less than one	mineral void	composite (ie synthetic mineral)	mineral (eg clay)	nil data	nil data	nil d.
SE 179 321	West Yorkshire JWMD	yes	nil data	**** inc. H	nil data	other	nil data	nil data	nil data	nil data	nil d.
SU 020 710	Wiltshire County Council	yes	municipal	**** inc. H	2-5	mineral void cellular filling containment	mineral (eg clay etc.)	mineral (eg clay)	no	nil data	nil d.
SU 086 888	Wiltshire County Council	yes	co-disposal municipal	**** inc. H	less than one	mineral void cellular filling containment	mineral (eg clay etc.)	mineral (eg clay)	no	nil data	nil d.
SU 015 712	Wiltshire County Council	yes	municipal	*** inc. H	2-5	mineral void cellular filling containment	mineral (eg clay etc.)	mineral (eg clay)	no	nil data	nil d
ST 880 528	Wiltshire County Council	yes	inert municipal	*** inc. H	5-10	mineral void	mineral (eg clay etc.)	mineral (eg clay)	no	nil data	nil d

Leachat	Gas Manager	Syste	If Yes	Poll	If Yes	Pallu	Pollu	Tippin	Landfill	Future Poll	Disposa	Disposa
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
nil data	passive, vented active, to flare or process	occasional	nil data	yes	gas	yes	nil data	0 years	nil data	landfill	LAWDC	yes
public sewer	passive, vented	occasional	leachate	nil data	leachate	no	no	nil data	containment	nil data	LAWDC not confirmed	nil data
public sewer	passive, vented	never	nil data	nil data	nil data	nil data	nil data	1-2 years	containment	landfill transfer	LAWDC	yes
public sewer	passive, vented active, to flare or process active, to turbine(energy)	never	nil data	no	nil data	nil data	nil data	2-5 years	containment	landfill	NAWDC	yes
none	passive, through cover	nil data	nil data	no	nil data	nil data	yes	2-5 years	containment	landfill	LAWDC not confirmed	yes
tanker collection	nil data	nil data	nil data	nil data	nil data	nil data	nil data	unknown	containment co-disposal	landfill	LAWDC not confirmed	yes
recirculation	passive, vented	never	nil data	nil data	nil data	nil data	nil data	nil data	nil data	landfill	NAWDC	yes
nil data	nil data	nil data	nil data		nil data	nil data	nil data	0 years	nil data	nil data	nil data	nil data
public sewer	passive, through cover	never	nil data	nil data	nil data	nil data	nil data	1-2 years	containment co-disposal	recycling landfill transfer	LAWDC not confirmed	yes
recirculation	passive, vented	nil data	nil data	nil data	nil data	nil data	nil data	nil data	containment co-disposal	landfill	NAWDC	yes
recirculation	passive, vented	never	nil data	nil data	nil data	nil data	nil data	unknown	containment	nil data	NAWDC	yes
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	0 years	containment	landfill	LAWDC not confirmed	yes
nil data	active, to flare or process	nil data	nil data	nil data	nil data	nil data	nil data	1-2 years	nil data	nil data	LAWDC not confirmed	yes
tanker collection recirculation	passive, vented	never	nil data	nil data	nil data	nil data	nil data	2-5 years	containment	recycling landfill transfer	LAWDC not confirmed	yes
public sewer	passive, vented	often	gas	yes	gas	no	nil data	0 years	containment	nil data	LAWDC	yes
none	passive, through cover	nil data	nil data	yes	nil data	nil data	nil data	2-5 years	nil data	nil data	LAWDC not confirmed	nil data
public sewer tanker collection	passive, vented	never	nil data	no	nil data	nil data	yes	2-5 years	nil data	landfill	LAWDC not confirmed	nil data
public sewer	passive, vented	often	gas	yes	gas	no	nil data	0 years	nil data	nil data	LAWDC	yes
recirculation	passive, vented	never	nil data	nil data	nil data	nil data	nil data	0 years	containment	recycling landfill transfer	nil data	nil data
tanker collection	passive, vented	never	nil data	nil data	nil data	nil data	nil data	0 years	nil data	landfill	NAWDC	yes
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data
on-site treatment public sewer	passive, vented	occasional	leachate	no	nil data	yes	yes	5-10 years	nil data	minimisation recycling composting incineration landfill transfer	not confirmed	yes
consented outfall recirculation on-site treatment	passive, vented	never	nil data	no	nil data	nil data	nil data	2-5 years	containment	landfill	nil data	nil data
public sewer	passive, vented	occasional	basal seal	no	nil data	yes	yes	more than ten	containment	landfill	NAWDC	yes
recirculation tanker collection	active, to flare or process	occasional	gas	maybe	gas	yes	yes	5-10 years	containment	recycling landfill	not confirmed	yes

Grid Re	Waste t	Licen	Waste T	Site ne	Void Sp	Design Co	Basal Seal	Capping La	Use o	H	Base
ST 957 620	Wiltshire County Council	no	inert	**** inc. H	less than one	landraise dilute and disperse	none	no cap(but soil shale cover)	no	nil data	nil da
SU 086 888	Wiltshire County Council	yes	co-disposal	**** inc. H	less than one	mineral void cellular filling containment	mineral (eg clay etc.)	mineral (eg clay)	no	nil data	nil da
SU 220 178	Wiltshire County Council	yes	municipal	**** inc. H	less than one	dilute and disperse	mineral (eg clay etc.)	mineral (eg clay)	no	nil data	nil da
SU 220 178	Wiltshire County Council	yes	municipal	**** inc. H	1-2	mineral void	mineral (eg clay etc.)	mineral (eg clay)	no	nil data	nil da
SU 213 343	Wiltshire County Council	yes	municipal	*** inc. H	less than one	dilute and disperse landraise	none	reconditioned natural soil	no	nil data	nil da
SU 127 911	Wiltshire County Council	no	municipal	**** inc. H	1-2	containment landraise cellular filling	mineral (eg clay etc)	mineral (eg clay)	no	nil data	nil d.
SU 191 561	Wiltshire County Council	yes	municipal co-disposal	**** inc. H	less than one	dilute and disperse landraise cellular filling	none	other..........................? no cap(but soil/shale cover)	no	nil data	nil d.
SJ 330 570	Wrexham Maelor Borough Council	yes	inert municipal	**** inc. H	2-5	mineral void cellular filling containment	bentonite enhanced soil composite (ie synthetic mineral)	not confirmed	no	nil data	nil d.
SJ 331 573	Wrexham Maelor Borough Council	no	inert municipal	**** inc. H	2-5	mineral void cellular filling containment	mineral (eg clay etc)	composite(synthetic/mineral)	no	nil data	nil d.
SJ 302 445	Wrexham Maelor Borough Council	yes	inert municipal	**** inc. H	less than one	mineral void containment	mineral (eg clay etc)	mineral (eg clay)	no	nil data	nil d.
SH 531 755	Ynys Mon Borough Council	nil data	nil data	*** inc. H	nil data	nil data	nil data	nil data	nil data	nil data	nil d.

none	passive, through cover	never	nil data	no	nil data	nil data	nil data	0 years	containment	minimisation recycling composting landfill	not confirmed	nil data
consented outfall on-site treatment	passive, vented	never	nil data	no	nil data	nil data	nil data	2-5 years	containment	landfill	nil data	nil data
recirculation	passive, vented	never	nil data	no	nil data	nil data	yes	0 years	containment	minimisation recycling landfill	nil data	nil data
recirculation	passive, vented	occasional	leachate	maybe	leachate	nil data	yes	5-10 years	dilute and disperse	recycling landfill minimisation	not confirmed	yes
none	passive, through cover passive, vented	never	nil data	no	nil data	nil data	nil data	0 years	containment	transfer landfill	not confirmed	yes
on-site treatment recirculation	active, to flare or process	never	nil data	no	nil data	nil data	nil data	5-10 years	containment	minimisation recycling composting incineration landfill transfer	not confirmed	yes
none	passive, through cap passive, through cover	never	nil data	no	nil data	nil data	yes nil data	0 years	nil data	transfer landfill	not confirmed	yes
tanker collection recirculation	active, to flare or process	occasional	gas	nil data	nil data	yes	nil data	5-10 years	containment	landfill	NAWDC	yes
tanker collection recirculation	active, to flare or process	occasional	gas	maybe	gas	yes	nil data	0 years	dilute and disperse containment	landfill	NAWDC	yes
tanker collection recirculation	active, to flare or process	occasional	gas	no	nil data	yes	nil data	1-2 years	containment	landfill	NAWDC	yes
nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data	nil data

APPENDIX 8

Summary Details - EfW Facility, Colnbrook, Berkshire, UK

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Non- Technical Summary of Environmental Statement

Prepared by:

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Introduction

1 S. Grundon (Waste) Ltd. (referred to in this document as Grundon) is seeking consent to develop its existing waste management facility at Lakeside Road Industrial Estate, Colnbrook, Berkshire. The Estate is located between the M4 and the A4, west of the M25. Lakeside Road has direct access to the A4 (see Figure 1).

2 Grundon propose to construct a new energy from waste (EfW) facility with a capacity to process up to 440,000 tonnes per annum of household, commercial and industrial waste. The facility will serve a catchment area including slough, other unitary authorities in Berkshire and parts of Buckinghamshire, surrey and London. A Visitor Centre to serve the EfW facility and provide facilities for environmental studies is proposed on Orlitts Lake South. The EfW facility can be served by rail by a new siding from the Colnbrook Branch Line, which passes alongside the site.

3 A planning application for the new facility has been submitted to Slough Borough Council and an application for Integrated Pollution Control (IPC) Authorisation has been made to the Environment Agency.

4 As required by the Town and Country Planning (Environmental Impact Assessment) (England and Wales) Regulations 1999, the planning application is accompanied by an environmental statement (ES). This document summarises the findings and conclusions of the ES in non-technical language.

5 5. Grundon agreed the scope of the ES with Slough Borough Council following consultation with other statutory bodies, including the Environment Agency and interested groups. The ES is based on the results of studies of potential environmental impacts, which have been carried out by specialist consultants. It sets out the results of an assessment of the likely impact of the proposals on the environment. The ES also explains why the scheme is needed, the consideration given to alternative sites, and describes measures proposed to reduce any environmental impacts.

6 In carrying out the environmental assessment, account has been taken of the potential implications for Grundon's proposal of other major development proposals in the area, including a fifth Heathrow Terminal, the associated proposals for a Logistics Centre and for Iver South Wastewater Treatment Works, and the London International Freight Exchange.

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Need for the Scheme

7 Grundon's proposals have been prepared to meet the need for sustainable waste management as part of a strategy of waste minimisation, recycling and energy recovery. Heat and power will be recovered from the waste in an EfW plant and the residue (which will be much smaller than is currently the case without EfW) sent to either for further use or to landfill. The proposed EfW facility will produce 30 Megawatts of electrical power, which will be transferred to the National Grid. This is enough electricity for 30,000 households.

8 The Government sees a national role for EfW in the implementation of both sustainable waste and energy strategies. It advises that, "alongside a move to higher level of recycling, a move to a higher level of incineration with energy recovery is necessary over the next 10-15 years in order to develop a more sustainable waste management system" (Less Waste More Value, 1998).

9 The benefits of EfW are that it:

i. complements the expansion of recycling;

ii. reduces the volumes of unrecyclable waste;

iii. enables landfills to be more easily managed;

iv. recovers energy;

v. is cost-effective;

vi. is safe and reliable, and

vii. provides long-term security.

10 There are at present no EfW plants in the South East outside London. It is inevitable that some will be needed if the Government is to achieve its target of reducing the dependence on landfill. To ensure economic viability, an EfW plant may serve a wider area than a single waste disposal authority.

11 Regional waste planning guidance for London and the South East advocates self sufficiency at county level, a reduction in export of untreated waste from London to zero by 2010 and the landfill of only residues from recycling and non-inert waste after 2010. The strategy relies on the diversion of waste from landfill by providing reduction, treatment and disposal facilities for non-inert wastes allowing landfill to deal with the remaining waste.

12 In common with authorities in the rest of South East England, waste disposal authorities in the former county of Berkshire continue to dispose of most of the community's waste by landfill. Former Berkshire authorities currently export substantial quantities of their communities' waste out of their areas for landfill elsewhere.

13 The Berkshire Waste Local Plan is the statutory plan for the former county. It recognises that recycling and EfW are compatible and aims by 2006 to phase out landfill on Berkshire and the use of landfill outside the county for the disposal of Berkshire's waste.

14 The Local Plan's strategy is based on the availability of adequate landfill capacity and the successful implementation of 'industrial reprocessing' proposals. Approaching half way through the plan period, landfill is in much shorter supply than anticipated and household and other non-inert waste is still exported to other counties in the South East. The 'industrial reprocessing' proposals which were intended to facilitate the reduction in landfill have failed to materialise, placing considerably greater pressure on scarcer landfill resources.

15 No viable alternative could be identified to replace the role of EfW in resolving the waste and energy recovery issues that are faced in the former county of Berkshire and the rest of the South East. Landfill is not an acceptable long term option. The extent of current reliance on landfill, and its growing scarcity, strongly suggests that the Lakeside EfW facility should be of a sufficient size to help meet the needs of an area wider than the former county of Berkshire.

16 With direct access via the A4 to a wide network of principle roads, Grundon's Lakeside Road site already helps serve the waste management needs of waste disposal authorities in the former county of Berkshire, western parts of Surrey, South Bucks and west London. None of these areas has current proposals for EfW plants, although the draft Surrey Waste Local Plan suggests that one or more are required.

17 The environmental assessment therefore concluded that there is an urgent need for the Lakeside EfW facility to be provided as part of sustainable waste management and energy strategies for waste disposal authority areas in the former county of Berkshire and adjoining areas.

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Alternatives

18 The only realistic alternative to the proposal is an EfW plant on another site. The Berkshire Waste Local Plan includes a list of criteria which has been used to identify preferred locations for such a plant.

19 The criteria include:

large catchment area close to major sources of waste.

within or adjacent to industrial type development

access to the primary road network

avoidance of sensitive landscapes

close links to the National Grid and the potential to develop district heating systems.

20 The Government's White Paper on sustainable transport states that sites should be served by rail,

21 The Lakeside site meets the Local Plan criteria and can be serviced by rail. The site is already used for waste management and is on an industrial estate with direct access from the primary road network.

22 Before confirming the suitability of the Lakeside site. Grundon considered industrial estates in Slough, Langley, Colnbrook, Poyle, Stockley Park, Hillingdon, Iver and Uxbridge.

23 The Berkshire Waste Local Plan does not identify any sites for EfW in east Berkshire. In central and west Berkshire, it identifies possible sites for EfW at Smallmead, Reading, and Colthrop, Newbury.

24 The potential catchment area of Colthrop is limited. Part of the Smallmead allocation has already been developed and the site is not served by rail. Compared to the Lakeside site, Smallmead is less well located to serve the sub-regional catchment area.

25 The analysis of alternative sites concluded that none could be found which have any advantages over the Lakeside site as a location for an EfW facility.

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[Site layout and Design],[35],[36],[37],[Temporary Construction Compound],[38],[Visitor Centre],[39],

[Liaison Group],[40],[41],[Construction Programme],[42],[NEXT...Issues]

The Scheme

26 The Grundon site at Lakeside Road currently houses a clinical waste incinerator (CWI) with a single chimney stack, a high density baling plant, a materials recovery facility (MRF), a vehicle workshop and offices.

27 Grundon already has consent to import and process 400,000 tonnes of waste per annum at its Lakeside Road site. To accommodate this volume, the company has consent to extend the existing MRF. Separately, it also has consent to increase the capacity of the existing CWI.

28 The proposed scheme will replace the consented materials recovery and waste reduction facility (a process which is currently followed by landfill) with a waste and energy recovery facility of similar capacity.

29 The CWI will be relocated and rebuilt within the site and clinical waste operations will continue throughout the construction period.

Description of the Proposals

Energy from Waste Facility

30 The EfW plant will be capable of processing approximately 440,000 tonnes of domestic, commercial and industrial waste per annum. Energy from the waste incineration process will be recovered and used to generate electricity. The plant will also be designed to facilitate the supply of heat to third parties as opportunities are identified.

31 An integral MRF within the EfW plant will also process mixed recyclable waste collected from households and commercial premises.

32 The existing CWI at Colnbrook provides a strategically important facility for the disposal of clinical wastes. The new CWI will provide updated facilities to treat the same range of wastes as the company's existing plant thus providing continuity of the current service.

33 The EfW and CWI plants will be designed to meet the latest emission limits as defined by European Directives on the Incineration of Wastes and the Environment Agency and will utilise the latest proven technology.

34 Grundon aims to develop a rail from the EfW plant to enable the Colnbrook Branch Line to be used for the import of wastes to the facility and the removal of residues, mainly ash.

Site Layout and Design

35 The design and location of the facility has been influenced by environmental and physical constraints and air traffic safety considerations. The proposed site layout is indicated in Figure 2.

36 The principal new buildings at the Lakeside site will be the EfW and CWI plants and a new chimney stack 75 metres high, serving both plants. A section through the EfW plant is shown in Figure 3.

37 The height of the building housing the EfW plant will be 42 metres. This is the minimum height required to house the enclosed plant, and complies with advice from the Civil Aviation Authority.

Temporary Construction Compound

38 Part of Tanhouse Farm Landfill, a completed landfill to the west of the site, will be used temporarily for the storage of materials and equipment, contractors parking and offices during construction of the facility.

Visitor Centre

39 The proposals include the development of a Visitor and Environmental Study Centre on the south western edge of Orlitts Lake South. The centre will provide an educational facility for waste management (which is now part of the national curriculum). Because of its setting, the Centre will also be ideally situated to study the value of urban wildlife sites. The location of the Visitor Centre and an elevation of the building are shown in Figure 4.

Liaison Group

40 Grundon will set up a Local Liaison Group as soon as practicable. The purpose of the liaison group will be to provide a forum for discussing construction/operation of the plant and management of the Visitor Centre.

41 The membership of this group will include representatives from Grundon, the Environment Agency, English Nature, Members of local councils and other elected bodies.

Construction Programme

42 Construction of the scheme will take approximately 31 months, with 3 months for commissioning of the EfW plant.

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Identifying the Environmental Issues

43 Following an analysis of the local planning policies and environmental constraints (see Figure 5) and consultations with the planning authorities, English Nature and the Environment Agency, it was decided that the environmental assessment should examine the effects of the proposals with respect to the following issues:

Air Quality
Water Environment
Ground Contamination
Landscape
Traffic
Noise and Vibration
Ecology
Recreation
Archaeology

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[52],[53],[54],[Ground Contamination],[55],[56],[57],[58],[Landscape],[59],[60],[61],[62],[63],

[64],[65],[66],[67],[NEXT...Impacts..contd.]

Assessment of Environmental Impacts

Air Quality

44 The air quality impact of the proposed EfW facility has been assessed with reference to current and proposed air quality standards and objectives.

45 Measurements from local monitoring sites show that the air quality in the vicinity of the Lakeside site generally meets air quality standards. However, the stringent air quality standards for nitrogen dioxide and particulate matter (substances present in the air emissions in the form of small particles) are not currently met close to major roads (including the M4 and M25) and Heathrow Airport.

46 The potential impact on air quality of emissions from the proposed EfW facility was assessed using a dispersion model. The results show that, in general, the contribution from the EfW facility to air pollution is not likely to be significant and is unlikely to result in increased risk to human health.

47 The assessment also shows that odorous emissions from the chimney stack and from handling and storage of waste will not be sufficient to cause odour nuisance.

48 Measures will betaken to control dust generation during demolition of the old plant and construction of the new plant. The release of dust from waste and ash handling will be prevented during operation of the plants.

Water Environment

49 The nearest watercourse to the site is the Colne Brook, which is about 200 metres from the EfW site, west of the proposed Visitor Centre. To the east is the Wraysbury River. There are a number of licensed surface water and groundwater abstractions within 2km of the site. However, none of these are used for public or private water supply.

50 The potential impacts on groundwater and surface water resulting from the construction and operation of the proposed EfW facility were assessed. Account was taken of water quality, drainage, water abstraction areas and floodplain areas.

51 Borehole investigations, carried out as part of the assessment, indicate that groundwater quality beneath the site appears to be good and that landfills in the vicinity of the site do not appear to significantly influence groundwater quality.

52 Construction works will affect local groundwater flows and levels during excavation activities and de-watering. However, with mitigation measures in place, the assessment concludes that the quality of the nearby surface water courses, and nearby abstractions will not be significantly affected by construction activities.

53 The operation of the new EfW facility will not result in any discharge of process effluent to sewers or local watercourses. Measures will be implemented to ensure that surface water drainage is of adequate quality prior to discharge and storage areas for oils and chemicals will be fully enclosed to contain any leaks and spills. Therefore, there are not expected to be any changes to the quality of groundwater or surface water resources.

54 although the development may result in the slight loss of below ground floodplain storage capacity due to excavation works, the development of the site is not expected to affect flood risks.

Ground Contamination

55 Historical records show that the Lakeside site was used for gravel extraction and the construction of pre-cast concrete units prior to the 1970s when Grundon developed their waste reclamation plant. Records do not indicate any former uses which could give rise to potential concern of ground contamination.

56 Information obtained from the Environmental Agency indicates that there are a number of commercial, industrial and domestic landfills within 250 metres of the Lakeside site. There is no evidence to suggest that the Lakeside site is influenced by adjacent landfills.

57 In the unlikely event that ground contamination is encountered at the site during construction of the EfW facility, appropriate remedial action will be taken in line with the relevant guidelines.

58 The risk assessment concluded that there are not likely to be any significant effects on the health and safety of site workers, on surface water or groundwater, arising from contamination at the site.

Landscape

59 The EfW site is surrounded by but lies outside the Green Belt designation. Tanhouse Farm Landfill, which will accommodate the construction compound, and the site of the Visitor Centre fall within the Green Belt designation.

60 The EfW plant, itself does not have a direct impact on the Green Belt. Although visible over a long distance, the careful design of the building and proposed landscaping will provide an attractive feature which in its setting against existing industrial buildings, pylons, motorway and rail infrastructure will not have an adverse impact on the openness of the Green Belt.

61 Once construction is completed, Tanhouse Farm landfill will be restored and the proposed planting will enhance

the landscape of this part of the Green Belt.

62 The small scale of the proposed Visitor Centre means that it will not affect the function of the Green Belt in checking unrestricted growth of large built up areas and safeguarding the countryside from encroachment. Part of its purpose is to provide access to the lake areas and their nature conservation interest fulfilling some of the objectives of the Green belt. The proposed planting round the lakes will also further enhance the landscape of the Green Belt.

63 The Lakeside site lies within the Colne Valley Regional Park. The redevelopment of the existing waste management site limits the potential impact on the park area. The Visitor Centre will provide public access to the park with the opportunity to observe wildlife on the lakes and in the surrounding area. Landscaping proposed as part of the scheme will also enhance this part of the park area.

64 The EfW building has been designed to produce the minimum size of building required to house the internal plant and to reduce the perceived mass of the building within the landscape. The Visitor Centre has been designed to reflect the appearance of the EfW plant. Landscape planting is proposed around the EfW site, Orlitts Lake South and North Tanhouse Farm Landfill to assimilate the development into the surrounding environment.

65 The landscape within which the Lakeside EfW site lies reflects evidence of past disturbance, with damaged and degraded land use components. Transportation corridors, utilities and industrial developments are the dominant and intrusive elements along with other urban infrastructure. The proposals will not introduce an entirely new element into the existing landscape but replace the existing waste management plant and chimney stack with a more prominent and larger facility within an existing industrial elements will also remain dominant within the study area.

66 The Lakeside EfW facility will be a substantial structure, visible from a wide area. However, it will frequently be seen in the context of other industrial and urban structures. From most public vantage points it will be a distant feature. Nevertheless, its scale means that it will be more prominent from closer viewpoints. As the facility will be visible from a number of viewpoints, it has been designed to be an attractive landmark building.

67 The overall conclusion of the assessment is that the EfW facility will not have a significant impact on the character or quality of the landscape and in particular will not affect the openness of the adjoining Green Belt.

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[Noise and Vibration],[75],[76],[77],[78],[Ecology],[79],[80],[81],[82],[83],[84],

[85],[86],[87],[Recreation],[88],[89],[90],[91],[92],[Archaeology],[93],[94],[NEXT...Conclusion]

Assessment of Environmental Impacts

Traffic

68 During construction, access to the temporary working compound at Tanhouse Farm and the Lakeside EfW site will be from the A4 trunk road via Lakeside Road (i.e. the existing access to the site). This access will also be used once the EfW facility is operational. A further access from Lakeside Road will provide access to the CWI plant. an existing private track off Lakeside Road will be realigned to provide access to the Visitor Centre.

69 The EfW facility will operate 7 days a week, 24 hours a day. Only 10% of the weekly traffic will arrive and apart from the site during the week-end and only 10% of daily traffic will arrive and depart during the night. It is considered that this volume of traffic will not have a significant impact.

70 Existing 12 hour (7a.m.-7p.m.) daily traffic flows to the site are 344 goods vehicle (HGV) movements and 120 light vehicle(cars and vans)movements. Grundon has consent to extend the CWI and MRF. There would be an average of 740 HGV movements and 211 light vehicle movements per day if these consents were implements.

71 During the construction phase for the EfW facility, HGV movements will be significantly less than the current 344 daily HGV movements generated by the site.

72 During the week the operation of the EfW facility would generated 524 daily HGV movements and 80 light vehicle movements. This is less HGV traffic than the site would generate if CWI and MRF were extended in accordance with existing consents and authorisations.

73 Whilst the operation of the EfW facility will result in an increase in traffic using the Lakeside Road/A4 junction, the effects of this increase on the local highway network are not considered to be significant and the junction will be functioning well within capacity.

74 The site can be served by rail from the Colnbrook Branch Line. The predicted volume of road traffic will be significantly reduced if the rail operating companies can provide a rail service to the EfW facility.

Noise and Vibration

75 Noise monitoring was carried out at four locations to represent the residential areas of Poyle and Colnbrook.

76 The assessment shows that noise levels generated during the construction phase will generally be less than the existing day-time noise levels which are dominated by traffic and aircraft movements.

77 The assessment proposes a noise limit from operational plant which will mean that operation of the plant will not have any significant noise impact during normal operation.

78 There may be some noise associated with plant commissioning and testing. Local residents will be notified of any noisy testing via the Liaison Group.

Ecology

79 As the EfW facility could potentially alter air emissions from the site, the effects of the proposal on the ecology of a wide area were assessed.

80 The site of the proposed EfW facility has no ecological value as it is already a developed industrial site.

81 The site for the Visitor Centre car park is characterised by urban wasteland vegetation and is of low ecological value.

82 Four sites of international conservation significance lie within 20km of the proposed development. Windsor Forest and Great Park candidate Special Area of Conservation (cSAC) is 8km to the south west and Burnham Beeches cSAC is 11km to the north west. The proposed Thames Basin Heaths Special Protection Area (SPA) lies 20km to the southwest of the site.

83 The lakes adjacent to Lakeside Road, Colnbrook, are being considered for inclusion in the South West London Waterbodies potential SPA. This designation process is at a very early stage.

84 Four sites of national importance for nature conservation lie within 20km of the site. These are Staines Moor SSSI, Wraysbury and Hythe End Gravel Pits SSSI, Windsor Forest and Great Park SSSI and Burnham Beeches SSSI.

85 Slough Borough Council has identified the lakes of Lakeside Road as a non-statutory Wildlife Heritage Site, particularly for their population of Kingfisher.

86 The assessment concludes that neither construction nor operation of the EfW facility or Visitor Centre are likely to have a significant effect on designated or potential areas of nature conservation importance.

87 Emission to air during operation of the EfW plant are not considered likely to have a significant impact on the health of trees and plants.

Recreation

88 The proposed EfW facility is located within the Colne Valley Regional Park which is an important environmental resource for the surrounding urban areas. However, within the immediate surroundings of the

proposed development site, recreational facilities are limited to footpaths, bridleways and fishing for members of local angling clubs.

89 There are a number of proposals to improve recreational facilities close to the development site. These include a SUSTRANS cycle route and a Linear Park proposal.

90 During construction of the EfW facility there will be limited impacts on recreational users resulting from noise and traffic. Mitigation measures are proposed to ensure that disturbance is kept to a minimum.

91 As part of the proposals a Visitor and Environmental Study Centre will be provided on Orlitts Lake South. This facility will improve access to the lake and provide information and study facilities on the operation of the EfW facility and on the nature conservation interests in the area.

92 Grundon is also prepared to provide a bridge over the Colne Brook providing a footpath/cycleway link with the proposed Linear Park. This would enable the Visitor Centre to be accessed by foot and cycle. Secure cycle parking will be provided at the Centre.

Archaeology

93 A 1km study area was defined around the Lakeside EfW site. This area is generally of high archaeological interest. The Grundon site and its immediate surroundings have been extensively worked for gravel and filled. Consequently, the site's archaeological potential is negligible and no impact on archaeological sites is likely as a result of the proposed scheme.

94 A number of listed buildings and the Colnbrook Conservation Area lie within the study area. These are located at some distance from the site and it is considered that neither the buildings nor their settings will be adversely affected by the proposals.

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Conclusion

95 The establishment of an EfW facility at Lakeside Road would provide a waste treatment and recycling facility for Slough, Berkshire and a wider catchment area extending into Surrey, Buckinghamshire and Greater London.

96 The results of the environmental assessment show that, with mitigation measures in place, the proposal can be constructed and operated without any significant environmental effects.

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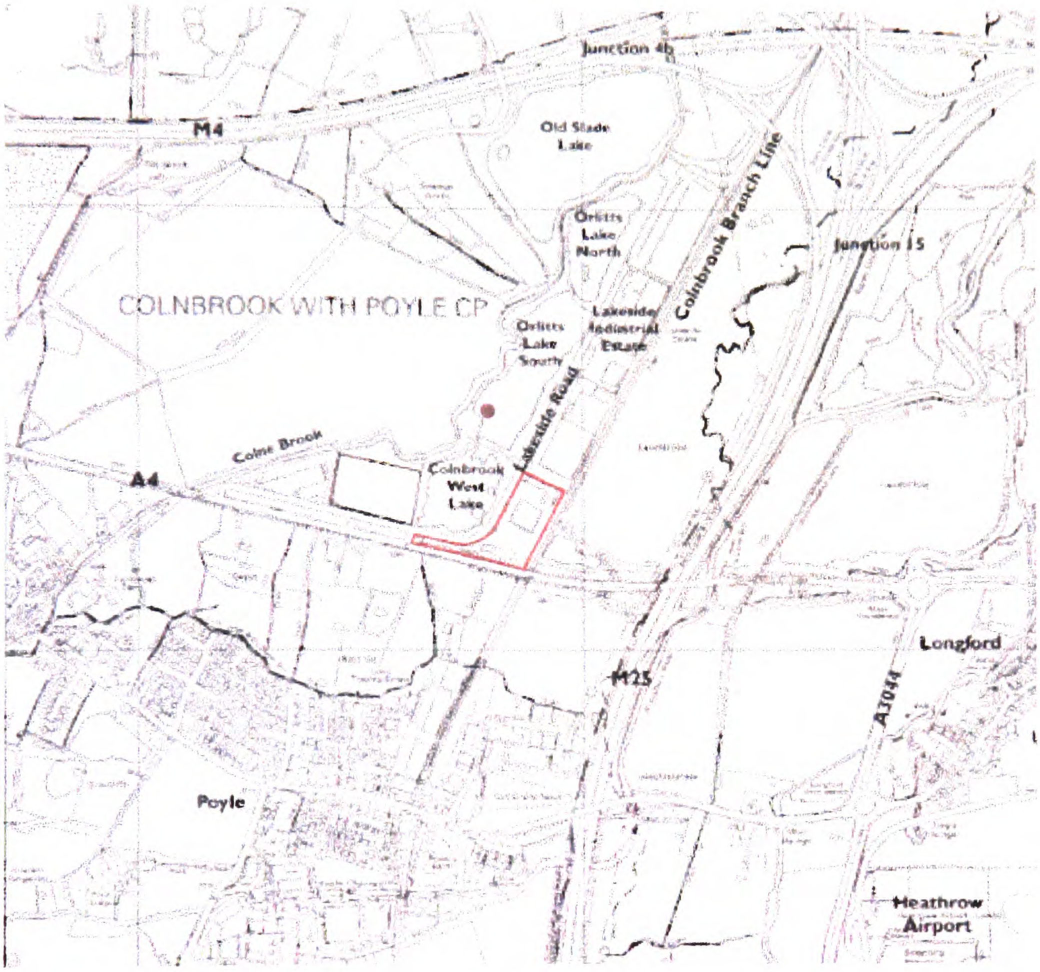
Figures

Figure 1 Site Location Plan



Proposed Lakeside Energy from Waste Facility

Proposed Temporary Construction Compound

Proposed Visitc Centre

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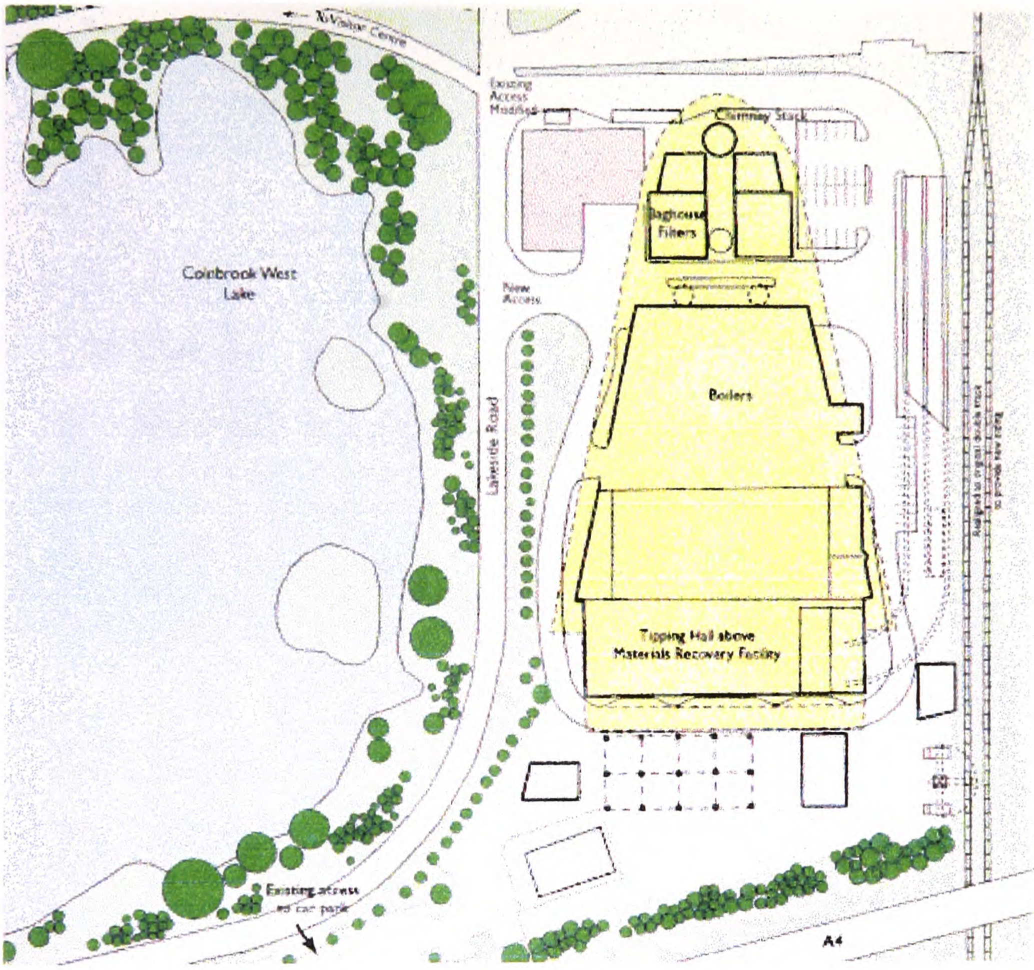
Figure 2 Site Layout



Clinical Waste Incinerator

Energy from Waste Plant

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Figure 3 Section through proposed Energy from Waste Plant

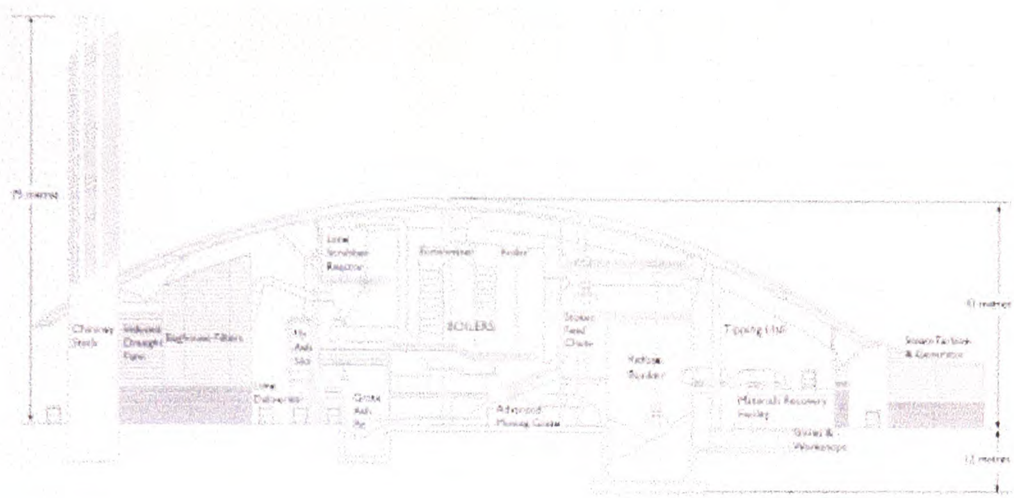

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Figure 4 Proposed Visitor and Environmental Study Centre

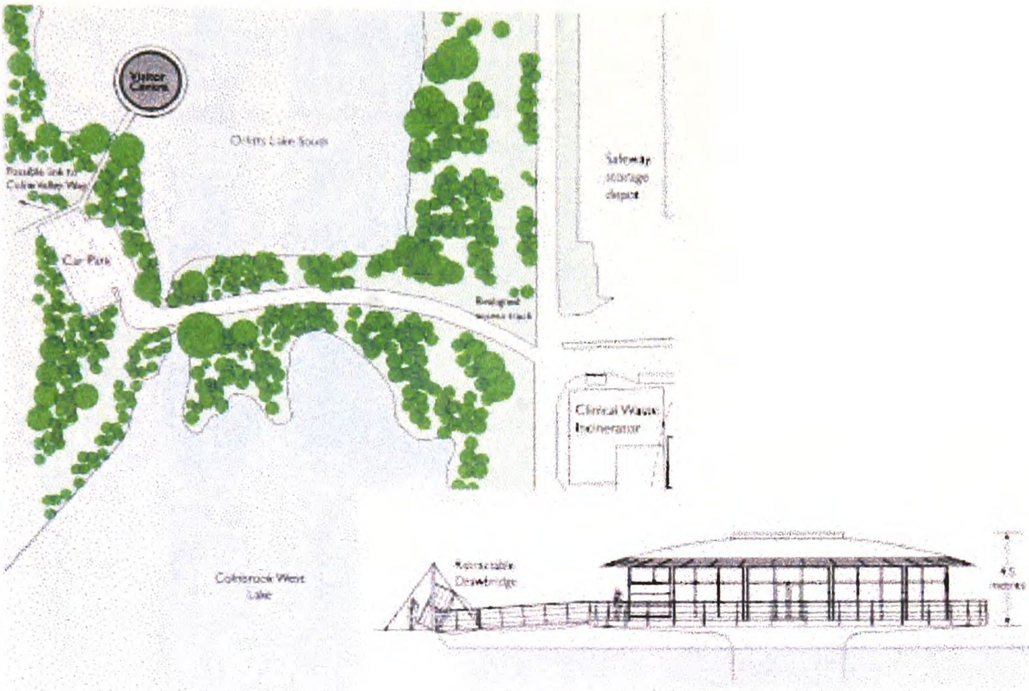

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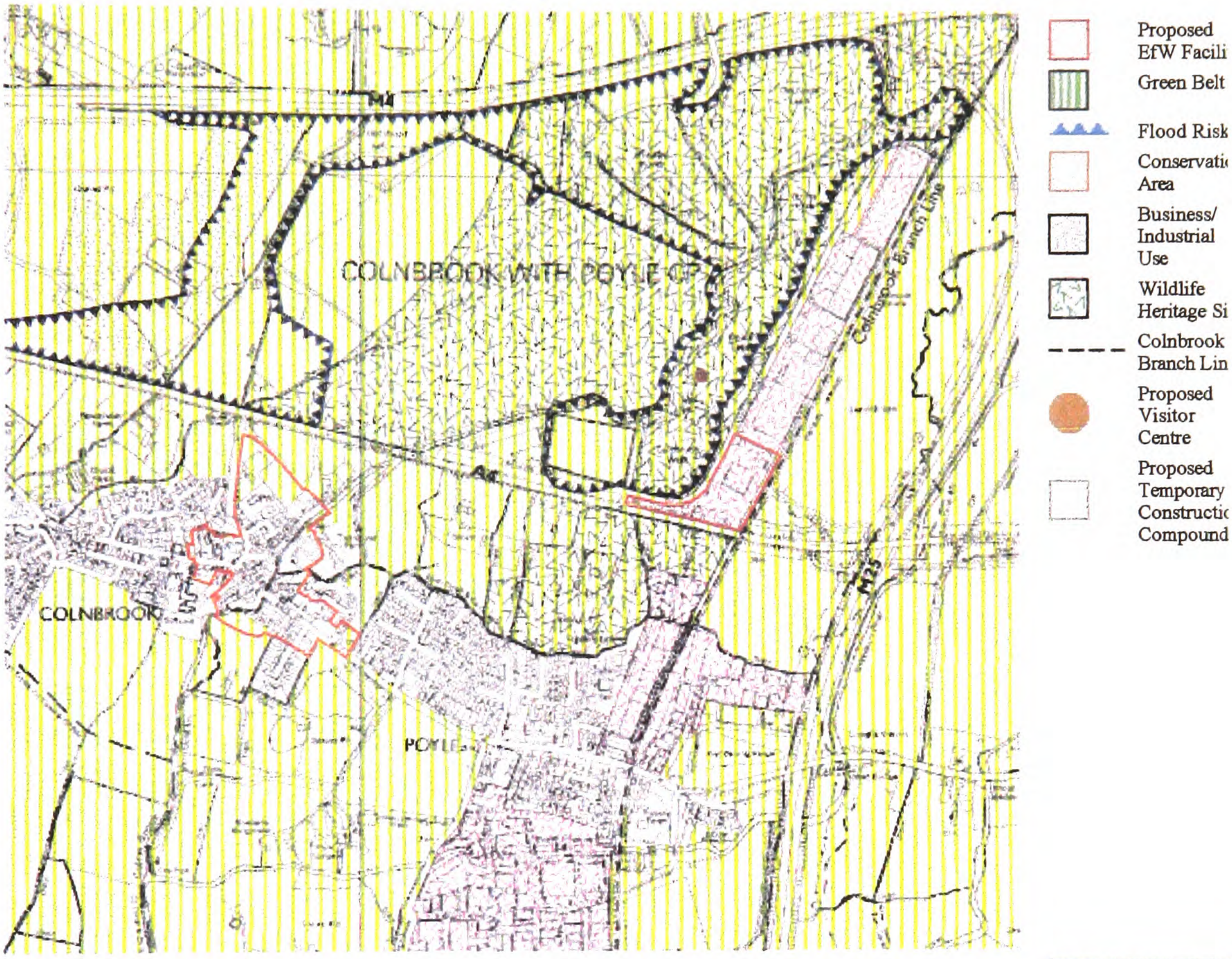
Figure 5 Planning Context



APPENDIX 9

HDPE - Final Considerations

HDPE - Final Considerations

Chemical Enemies of HDPE: The landfill industry currently views high density polyethylene (HDPE) as the favoured material for synthetic landfill lining systems. In the United States it has been used for this purpose since the early 1980's. The period of use in historic terms is relatively short.

A fundamental requirement for any landfill liner is a high resistance to chemical attack over a prolonged period of time - matched ideally to the duration of the hazard it is designed to contain. Against this background HDPE has been seen as the material of choice for synthetic liner systems, although other options are available.

It has been stated that HDPE "is not attacked by most inorganic chemicals and is insoluble in most organic solvents at room temperature". In a study of linear polyethylenes, only 14 out of 270 chemicals were rated as capable of causing, "upon prolonged exposure at room temperature, softening, embrittlement, or a significant loss of strength." The study referred to was undertaken by the Phillips Petroleum Company - a major plastics manufacturer for over 45 years.

Phillips' technical data identifies certain household chemicals that will degrade HDPE, permeating it, causing loss of tensile properties, softening it or introducing embrittlement or cracking. In fact it is the low stress crack resistance of HDPE that has been seen as a major drawback. Production of more conformable, lower density polyethylenes, has resulted for applications such as capping where accommodation of movements and changes in ground profile, arising from differential settlement, without overstressing of the geomembrane are vitally important. This is a key design issue which must be carefully considered - the matching of service conditions to material properties therefore needs thorough attention.

Two of the major classes of chemicals which are not compatible with HDPE are, aromatic hydrocarbons and halogenated hydrocarbons. The basic aromatic hydrocarbon is benzene (a major component of petroleum fuel). Other aromatic hydrocarbons include toluene and the three xylenes (o-, m- and p-xylene).

Naphthalene and p-dichlorobenzene are included in this class, which are known to permeate the HDPE product excessively. Of the halogenated hydrocarbons familiar names include carbon tetrachloride, trichloroethane, chloroform, DDT, aldrin, dieldrin, lindane, 2,4-D, 2,45-T, trichloroethylene, per-chloroethylene and so on. The full list is considerable and growing longer as chemists invent new ways to attach, chlorine, fluorine, bromine and iodine atoms to carbon and hydrogen.

Many everyday household chemicals are seen as incompatible with HDPE. This is important since many of these chemicals will find their way into the MSW waste stream and ultimately to MSW landfills lined with an HDPE geomembrane. Household chemicals which can cause stress cracking of HDPE include:-

ACIDS: Acetic acid (1% - 10% solution): aqua regia.
FOODS/FOOD PRODUCTS: cider, lard, margarine, vinegar, vanilla extract.
HOUSEHOLD TOILETRIES/PHARMACEUTICALS: detergents, dry cleaning fluids, hair oil, hair shampoo, hair wave lotions, hand creams, iodine, lighter fluid, nail polish, shaving lotion, shoe polish, soap, wax, amyl alcohol, ethyl alcohol, methyl alcohol, propyl alcohol etc.
OILS: castor, mineral, peppermint, vegetable, pine etc..

In addition to stress cracking, many of the chemicals listed will physically permeate the HDPE resulting in gradual loss of intact section often accompanied by softening, swelling and deformation of the HDPE.

The inference from the above is that it is highly unlikely that none of the above chemicals will find their way into MSW landfills. Aside from mixing of the different chemicals (possibly resulting in more aggressive compounds) it is clear that any HDPE liner will be under attack and effort must be directed to enhancing or augmenting those properties of HDPE which may give protection against these aggressive substances. (Rachel's Hazardous Waste News No. 117 21/2/1989)

Polymer Structure Weaknesses in HDPE: In understanding the potential for this chemical attack on HDPE, one must recognise that the building blocks of plastics are found in natural gas, coal, and wood - but the major source is oil. Oil (just as coal and natural gas) is a mixture of molecules of different sizes and structures. To separate out the different molecules crude oil is distilled at the oil refinery. The oil is boiled, separating lighter molecules from the larger and heavier molecules. These heavy molecules are then 'cracked' to break them up into smaller lighter molecules.

The distillation and cracking process produce organic chemicals (containing carbon and most commonly hydrogen, oxygen and nitrogen). It is these organic chemicals which are the key to the production of many modern pesticides, glues and plastics. Other chemicals, such as chlorine and lead, are added to enhance characteristics like strength, stiffness, colour etc. The organic chemical building blocks are then subjected to polymerisation to create the base plastic resin. Polymers are large, organic, chain like molecules made up of repeated units of smaller molecules. Polymerisation usually requires heat and the addition of catalysts. Catalysts are required to help the polymerisation process, but nevertheless, there is nearly always a need for a great deal of heat - to enable the basic building block molecules to be combined to form long chains. Because of the heat, the long chains may be susceptible to decomposition, even sometimes during manufacture, with defect points located along the chain. The point of defect is in the chemical bonds, which absorb the heat energy used in the manufacturing process. Considering the law of conservation of energy the amount of energy in a system after a reaction is the same as the amount of energy in the system before that reaction. In the case of HDPE the heat energy is contained, absorbed in the bonds between the atoms in the plastic. High energy bonds are seen as being less stable than low energy bonds. There is a danger in a high energy bonding system of the bonds breaking down spontaneously. These are the defect points in HDPE - and scientists have worked tirelessly to reduce the number of defect points. They have not been able to completely eliminate them but the overall service performance and durability of synthetic polymers continues to improve.

These physical and chemical defects serve to demonstrate the potentially fragile and unstable character of certain long chain molecules joined by high energy bonds. In addition, when the resin is further processed to become the finished product, additional defect points are created as the process includes additional heating and handling. Heat bonding of panel seams on site can lead to additional defect points.

In time plastics are susceptible to decomposition or 'aging' with molecules breaking apart spontaneously - commencing at the defect points. All plastics are known to 'age' - this being exhibited by embrittlement, loss of strength, cracking and fragmentation. All of these 'failure' modes have serious implications in landfill liner applications and this needs to be borne in mind in the selection of basal liner components, design and intended service life. (Rachel's Hazardous Waste News No. 217 23/1/1991). See also - (McKendry, P. J. (February, 1993))

APPENDIX 10

Compacted Clay Liners (CCLs) - Final Considerations

Compacted Clay Liners (CCLs) - Final Considerations

Compacted Clay Liners - Defects and Failure Mechanisms: In the American Chemical Journal - Environmental Science and Technology (March 1989), it was revealed that organic chemicals had been found to move through clay landfill liners much more rapidly than previously envisaged. These chemicals include benzene, toluene, trichloroethylene and ethyl benzene.

In investigating a five year old landfill in Ontario the research team found a rapid movement of organic chemicals through compacted clay. From their field research they produced mathematical and computer modelling scenarios which fit closely to their study observations. The computer models are now able to closely predict the time chemicals will take to pass through a typical clay landfill liner. They concluded that the mechanism of diffusion will move 'organics' through a 3 foot (0.9m) thick clay liner in approximately 5 years. They further concluded that significant quantities of 'organics' would continue to flow through the liner year after year.

There are two basic ways that chemicals move through clay; these are advection and diffusion. Advection is what may be considered the more 'normal' movement of fluids through soils. The fluids travel through the spaces between grains of soil. In the case of fine grained soils such as clays these spaces are much smaller than in say, a sand, making it more difficult for the fluid to pass through. However, the more pressure you apply to fluids, the faster (or more readily) the fluids will pass through. Because of its fine grained structure compacted clay has gained its reputation as a suitable material for lining landfills. The normally specified permeability (or hydraulic conductivity k) for a modern compacted clay liner is 1×10^{-9} m/s.

To ensure that pressure build up above the clay liner is controlled the depth of leachate fluid is not allowed to rise excessively - a typical limit would be say 1 foot (0.3m) depth in the US. Generally 1 metre depth of leachate is allowable in the UK and Europe - measured above the highest point of the liner. This ensures, in accordance with D'Arcy's Law, that the potential for leachate through flow within the clay is kept at an acceptable level.

However, the Canadian/American study suggests that diffusion may play a greater role in leachate flow through clay than previously thought. Diffusion or "Fickean" diffusion is linked to the constant motion of molecules - commonly called "heat". "Hotter" molecules are those moving more rapidly than "cooler" or slower molecules. Due to this motion of "heat", molecules tend to move from a more concentrated chemical solution. Hence, concentrated chemicals in landfill leachates will exhibit the tendency to migrate through landfill bottom liners.

At the time of the report the research team questioned whether enough emphasis was being placed by Engineers on the diffusion mechanism. They concluded that even a small landfill of say, 2.5 Hectares, had the potential to pollute groundwater with over 20Kg of benzene per year, year after year. They noted that 20Kg of benzene was sufficient to contaminate 3.8 Billion litres of groundwater up to the allowable drinking water standard criterion of 0.005 milligrams per litre (5 parts per Billion) applicable in the United States.

The report cited eight previous studies that had reached similar conclusions about diffusive transport of organic chemicals through clay. (Rachel's Hazardous Waste News No. 125 18/4/1989)

APPENDIX 11

Geosynthetic Clay Liners (GCLs) - Final Considerations

Geosynthetic Clay Liners (GCLs) - Final Considerations (Trauger, R. (1996))

GCLs - Design Considerations and Limitations: GCL installations are becoming increasingly popular as an alternative to compacted clay liners - their self healing properties make them attractive in landfill containment applications. GCLs may be commonly used on their own or in conjunction with a geomembrane liner as part of a composite or multi-barrier system. A popular reason for the selection of GCL is their ease of installation but this should not be construed as indicating that the design process for such installations is equally simple. GCLs require a unique design approach to ensure that they perform as intended.

The three "primary design elements" for GCLs are seen as:

- hydraulic performance
- slope stability
- chemical compatibility

Hydraulic Performance: The function of a GCL is to act as a barrier to liquids. An important stage in determining the long term performance of a GCL is to understand the service conditions to which the GCL will be exposed. Will the GCL be a single liner or part of a composite GCL/geomembrane system? and what will the confining stresses and hydraulic heads be in service? In addition will the GCL be subjected to dessication/rehydration and/or freeze/thaw cycles? The likelihood of differential settlement will also be of concern.

Koerner and Daniel (1994) have also considered other aspects of hydraulic performance relevant to waste containment applications. These include breakthrough time, solute flux and chemical adsorption capacity investigated by mathematical modelling of chemical transport mechanisms to safeguard the hydrogeological environment. It is recommended that a site specific examination of the hydrogeology of the site, along with the chemistry of the liquid waste, is needed to properly execute the mathematical models.

The contaminant transport behaviour of GCLs is largely unexplored, although it is generally believed that diffusion is the responsible transport mechanism for a modern liner system containing a GCL and/or a geomembrane. As diffusion only occurs in the presence of a concentration gradient it has been argued that this transport mechanism will exist over a relatively short time for thin geosynthetic barriers. Long term contaminant transport is understood to depend more on the properties of the soils beneath the liner system. For this reason, Koerner and Daniel have argued, in the current regulatory setting, that diffusion is not a significant factor in the overall design of a GCL based liner system.

Slope Stability: One of the most critical tasks in the design of a modern geosynthetic liner systems is to ensure that slope stability is maintained, particularly with composite or multi barrier installations. The inclusion of a GCL into the liner system may further complicate this task. Interface shear strength between a GCL and other geosynthetics depends upon highly variable parameters such as geosynthetic type, bentonite moisture content and confining stress.

GCLs are installed against soil layers and/or other geosynthetic products. Most GCL manufacturers can provide pertinent interface shear strength data that will give the designer a general idea of liner system stability. This data should be used as a preliminary screening tool to determine if the proposed slope and liner system is feasible. When the initial system design is completed, interface shear testing is recommended to verify that the system is stable with a suitable factor of safety allowance included. Standard test methods such as ASTM 5321 do not address many of the complexities of the GCL shear test, so the designer must provide additional information to the test house to ensure that the test data are meaningful. Additional information will include - GCL name and product, side of GCL to be tested, adjacent geosynthetic name/product and side in contact, direction of test. If testing against a soil then representative soils information including Proctor compaction data should be provided. Information on the hydration period and conditions including the confining stress under which hydration will occur is also pertinent. Any requirement for flooding of the test interface during shearing should also be defined together with rate of shear, total shear displacement and the normal stress to be applied during shearing. Once test data is collected it can be used in many of the useful mathematical modelling techniques developed for this application - see (Giroud and Beech (1989)), (Wilson-Fahmy and Koerner (1992)), (Long et. al. (1994)) and others.

Another important design consideration with respect to GCLs is the product's internal shear strength.. The first GCLs marketed in the mid 1980s were unreinforced, limiting the internal shear strength of the product to that of the bentonite layer. Applications for the product were extremely limited in slope applications due to the bentonite's low shear strength. This led to the introduction of reinforced GCLs in the late 1980s, as a result of which internal shear properties were significantly increased. These products allowed steep slope applications but they inevitably exhibit the "strain softening" that results in low post peak shear strength. Much debate now centres on whether stability of a GCL system should be evaluated on peak or post-peak shear strength.

Chemical Compatibility: A GCL needs to resist chemical attack when used in waste containment applications such as landfill basal liners.

Sodium bentonite which is hydrated and permeated with relatively clean water will be an effective barrier indefinitely. However, the inter layer sodium ions can be exchanged with other cations that may be present in the water during the hydration or permeation process. This type of exchange reaction greatly reduces the amount of water that can be held in the inter layer, resulting in decreased swell. Anions will also contribute to reduced swell. The loss of swell usually causes increased porosity and decreased performance as a hydraulic barrier. This is the primary mechanism for chemical contamination of bentonite. As reported by Trauger, other chemicals such as organic molecules are far less likely to affect bentonite and are seldom encountered in concentrations sufficient to pose a problem. Contaminants of concern include the cations of Calcium, Magnesium, Potassium, Ammonium, Sodium, Iron, Aluminium and the anions Chloride, Sulphate, Nitrate, Carbonate, Hydroxide.

Experience has shown that calcium is the most common source of compatibility problems for GCLs. Examples of liquids with potentially high calcium content include leachates from lime stabilised sludge, soil or fly ash; extremely hard water, harsh landfill leachates, and acidic drainage from Calcareous soil or stone.

Solid waste leachates generally do not cause compatibility problems. Ruhl (1994) measured the hydraulic conductivity of GCLs permeated with a variety of leachates. His tests showed GCLs to be essentially unaffected by the actual USA MSW leachates used, regardless of whether the GCLs were pre hydrated with clean water or with leachates immediately.

However, it is possible that certain soils can leach large quantities of calcium and/or magnesium in an acidic environment, resulting in the exchange reactions described above. This is a particular concern with GCLs, which may be sensitive to the chemical composition of the soil placed above it as in the protective cover to landfill caps. Where this is a concern a cations analysis of the soil is recommended.

Further observation from an extensive testing research programme has been offered by Daniel (Daniel D.E. 1996 Overview of Geosynthetic Clay Liners - Seminar at The National Motorcycle Museum, Birmingham, UK, 2 December 1996). On the chemical compatibility of GCLs he proffers the following opinion:

- Hydraulic conductivity of bentonite can be adversely affected by high salt concentrations, permeation with polyvalent cations such as Ca^{++} and permeation with concentrated organic chemicals.
- The effect of an incompatible chemical or leachate tends to be much more severe when the first wetting liquid is the leachate or chemical - bentonite is much more chemically resistant if hydrated in fresh water before exposure to the chemical or leachate.
- Dilute organic compounds are of little or no concern
- Destructive effects of chemicals are most pronounced at low compressive stress - at high compressive stress there is little or no harmful effect from nearly any chemical.

APPENDIX 12

Summary Details - The VAR Waste Facility, Netherlands

Integrated Systems: The VAR Facility, Netherlands - A Modern Waste Park
(National Recycling Directory (1995-1996), Waste Watch/LARAC)

Introduction: The Veluwsc Afval Recycling (VAR), located at Wilp, 7 km from Apeldoorn in the eastern Netherlands is the result of a long term vision. VAR is a 75 hectare site comprising an old landfill site, a concrete crushing plant, 2 composting plants, a waste sorting plant and a double lined landfill. The facility input is about 650,000 tonnes per annum but of this only 100,000 tonnes ends up in the landfill. Of about 50 concrete crushing plants in Holland, the VAR plant is typical in providing a range of products, either concrete or more usually a mixture of brick and concrete, in different size gradings. The products are sold for about £3-6 / tonne.

The VAR site: The site is entirely fenced and ringed by a road, built using materials from the concrete crusher. Most of the site is also surrounded by a 3 metre high bund which provides visual screening and which assists noise reduction. The facility comprises:

Concrete crusher, 250,000 tpa input - 35,000 tpa going to the landfill.
Composting plants, total capacity 230,000 tpa - minimal discard to landfill.
Sorting facility, 100,000 tpa input, 35,000 tpa to crusher, 25,000 tpa recycled, 45,000 tpa to landfill.
Landfill, double lined with plastic membrane and bentonite enhanced sealing layer.

Payments at the facility vary from as little as £1.65./tonne for pure concrete waste to £29.00./tonne for green (garden) wastes and £60.00./tonne for direct disposal to landfill. Annual costs per person for household waste management services in the area are about £125.00. - £145.00. per annum.

The old landfill at the site contains about 700,000 - 800,000 tonnes of waste in a design having no containment. The old landfill will be recycled as over half of its contents consist of stone materials, which can be reclaimed. There is also methane extraction for energy recovery at the old landfill. In total the VAR facility has a landfill capacity approaching 4M cubic metres - adequate for up to 40 years life at the current rate of disposal.

Composting system: The composting system used at VAR is a static pile with air sucked through 30m x 15m x 2m piles of green waste. The wastes are delivered in a variety of vehicles, coming from parks, individual households and also household segregated organic wastes. The wastes are mixed to provide an ideal carbon to nitrogen ratio of 20:1.

An air treatment plant initially presented problems, with complaints about strong smells from residents in a neighbouring hamlet, 500 metres away from the site. To counter this a new vacuum plant, the fourth to be used, was built in April 1994 - this is still in use.

The air is sucked down from the piles and treated with water which is maintained at an optimum temperature of 35°C by adjusting the flow of air in from the outside. This ensures that when evacuated air is put through the bio-filter the microbes in the bio-filter are working in ideal conditions of temperature and humidity. The bio-filter comprises a base of 20-40 mm sandstone chippings overlain by a mixture of 5% compost, bark and wood chippings which should last two years before it has to be incorporated into the composting process.

Waste is retained in the composting pile for three weeks, by which time the aerobic decomposition is complete. The waste is screened to remove all material over 12 mm before being moved to a windrow for a further 8 weeks to mature.

100,000 tonnes of compost is produced annually and this is sold in a variety of forms. There have been problems with storage due to the short sales period - March to June. In an attempt to overcome this and to add value to the product compost pellets are now being produced. These are aimed at the home gardener, with 15 kg bags selling at £6 each.

A total of 25 people are employed to undertake all the work associated with composting at the site. The total investment in composting facilities at the site to date is £12.5M.

The Sorting Centre: The sorting centre, the last element at the site to become operational, employs 10 people. Using a mixture of mechanical and hand sorting a wide range of materials including paper and cardboard, steel and aluminium etc. are processed - some for further processing at VAR and some for removal for further recycling elsewhere.

The Landfill: The new landfill facility is being built with a synthetic basal liner overlain by a bentonite enhanced layer to provide a double barrier against movement of leachate into groundwater. The landfill will eventually be built to a height of 30 m above normal surface level - a land raise. Landfill gas extraction equipment has been installed, including the use of old tyres laid horizontally for gas to be collected within them for efficient onward transmission to two generators, of 150 kW and 650 kW capacity. Ultimately the landfill will be capped with 1 - 1.5 m of soil cover and seeded with grass to be used as grazing for sheep.

Comment on VAR: The VAR facility is seen to offer BPEO for wastes generated in the immediate vicinity. It has great potential on the fringes of large urban areas. The operating philosophy at VAR also meshes closely with the latest guidance coming out of Brussels on sustainable waste management - namely, emphasis in waste recovery, pre-treatment of wastes (by composting) and disposal of a reduced volume and more benign waste residue to landfill allied with gas to energy power production.

Development of similar sustainable waste treatment and disposal systems within the UK should be encouraged. The introduction of the new EU Landfill Directive, with its emphasis on waste pretreatment may act as the legislative catalyst to bring this about. Support from local planning authorities will need to be canvassed with due allowance for the siting of such facilities made in the development of Local Plans.

REFERENCES

REFERENCES

- A Way With Waste (1999), UK HMSO.
- Agricola, K.R., Krause-Singh, J.M., Hauser, R.L. (May 1990) Chemical Effects on Flexible Membrane Liner Seams, Journal of Materials in Civil Engineering, Vol. 2 No. 2, pp53 - 71.
- Aitken, M., Roberts, I. (February 1993) Construction Quality Assurance of Composite Liners, Wastes Management, pp 35-36.
- Anex, R.P. (November 1996) Optimal Waste Decomposition - Landfill as a Treatment Process, Journal of Environmental Engineering, Vol.122, No.11, pp 964-974.
- Aspinwall Limited (1993). Site File Digest - for UK, Department of the Environment.
- Barron, J. (1995) An Introduction to Wastes Management, 2nd Edition, Chartered Institution of Water and Environmental Management.
- Beine, R.A., Dahlman, K. (1995) Capping of an Old Dump Containing Industrial Wastes, Waste Disposal by Landfill "Green '93, Bolton, UK", pp 517-522.
- Benson, C.H. (March1993) Probability Distributions for Hydraulic Conductivity of Compacted Soils, Journal of Geotechnical Engineering, Vol.119, No. 3, pp 471-486.
- Benson,C.H., Zhai, H., Rashad, S.M. (October 1994) Statistical Sample Size for Construction of Soil Liners, Journal of Geotechnical Engineering, Vol. 120, No. 10, pp 1704-1723.
- Bickerton, M., Davies, K., Larkin, J. (1995) Landfill Cover Performance - An Experimental Case Study, research report for U.K. DoE.
- Birchler, D.R, Milke, M.W., Marks, A.L., Luthy, R.G. (Sept/Oct 1994) Landfill Leachate Treatment By Evaporation, Journal of Environmental Engineering, Vol.120, No.5, pp 1109.
- Bowders, J.J., Usman, M.A., Gidley, J.S. (Undated) Stabilised Fly-ash For Use As Low Permeability Barriers, Energy Research Centre, West Virginia University, Project No. WUR-16-86, Waste Disposal Practice pp 320-333.
- Brandl, H. (1992) Mineral Liners For Hazardous Waste Containment, Geotechnique 42, No.1 pp 57-65.

REFERENCES (cont.)

- Cadwallader, M.W., Barker, P.W. (1986) Quality Control of Flexible Membrane Liners for Waste Disposal Facilities, Geotextiles and Geomembranes, pp 309-335.
- Carra, J.S. (1990) Municipal Solid Waste and Landfilling in the United States of America. In: Carra, J.S.; Cossu, R. (Eds.): International Perspectives on Municipal Solid Wastes and Sanitary Landfilling. Academic Press Inc. pp37-50.
- Chapuis, R.P. (1990) Sand-bentonite liners: Field Control Methods, Canadian Geotechnical Journal 27, pp 216-223.
- Commoner, B., Cohen, M., Woods Bartlett, P., Dickar, A., Eisl, H., Hill, C., Rosenthal, J. (1996) Dioxin Fallout In The Great Lakes, for Center For The Biology Of Natural Systems.
- Cossu, R., (1990) Sanitary Landfilling in Japan, from International Perspectives on Municipal Solid Wastes and Sanitary Landfiling, Academic Press Inc., pp 110-138.
- Daily Telegraph (Weekend) 29 March 1997, All Hands to the Dump pp 6.
- Daniel, D.E. (1990) Compacted Soil Liners - Summary Review of Construction Quality Control for Compacted Soil Liners, ASCE Geotechnical Special Publication No 26, pp 175-189.
- Daniel, D.E. (1995) Pollution Prevention in Landfills Using Engineered Final Covers, Waste Disposal by Landfill "Green '93, Bolton, UK", pp 73-92.
- Daniel, D.E. (1996) Overview of Geosynthetic Clay Liners, Seminar at The National Motorcycle Museum, Birmingham, UK, 2 December 1996.
- Daniel, D.E., Benson, C.H. (December 1990) Water Content- Density Criteria for Compacted Soil Liners, Journal of Geotechnical Engineering, Vol. 116, No. 12, pp 1811-1830.
- Daniel, D.E., Koerner, R.M. (December 1991) Landfill Liners from Top to Bottom. Civil Engineering.
- de Silva, M.S., Roberts R.D., Pearson, C.F.C., Nicholls, K. (1995) The Sustainable Landfill, Waste Disposal by Landfill "Green '93, Bolton, UK", pp 275-280.
- Di Stefano, A.B. (1993) Settlement of Beddingham Landfill, Engineering Geology of Waste Disposal, Geological Society, Engineering Geology Special Publication No.11, pp111-119.

REFERENCES (cont.)

- Di Stefano, A.B., Needham, A.D. (February 1994) Geosynthetic Lining of Steep Walled Quarry Landfills, Wastes Management, pp 26-29.
- Edil, T.B., Sandstrom, L.K., Berthouex, P.M. (September 1992) Interaction of Inorganic Leachate with Compacted Pozzolanic Fly Ash, Journal of Geotechnical Engineering, Vol.118, No.9, pp 1410-1430.
- Ella, P. Capping Systems (February 1993) Shanks & McEwan, Wastes Management, pp 38.
- ENDS 236 (Anon.) (September, 1994), Staking Out The Battleground Over The Future Of Landfill, Waste Management No. 105, pp17-20.
- ENDS 265 (Anon.) (February, 1997) Landfill Faces "Leap to Utopia" with Flushing Bireactors, pp12-14.
- ENDS 269 (Anon.) (June, 1997) Now or Never for "Flushing Bioreactor" Demonstration Plan, pp15-16.
- ENDS No.270 (Anon.) (July 1997) Recycling and Landfill Beat Incineration in “Greenhouse” League, pp12.
- Ewing, C. (February 1993) In House Landfill Design Using Bentonite Matting, Wastes Management, pp30.
- Fischer, D., Schenkel, W., (1990) Anforderungenan die Ablagerung von Abfallen in der Bundesrepublik, der Schweiz und Osterreich. Mull und Abfall 1, pp 2-13.
- Forster, A.M. (1) (1995) Landfill Cover Technology within the United Kingdom, the Rest of Europe and the United States, MRM Partnership, Waste Disposal by Landfill “Green ‘93, Bolton, UK”, pp 141-150.
- Forster, A.M. (2)(1995) Water Balance Evaluation of Different Multi-layered Final Cover Systems, MRM Partnership, Waste Disposal by Landfill "Green ‘93, Bolton, UK", pp 307-312.
- Giroud, J.P., Bonaparte, R. (1989) Leakage Through Liners Constructed With Geomembranes, Geotextiles and Geomembranes 8(1) (Part 1), pp 27-66 & 8(2) (Part 2), pp 71-111.
- Giroud, J.P., Khatami, A., Badu-Twenenboah, K. (1989), Evaluation of the Rate of Leakage Through Composite Liners, Geotextiles and Geomembranes 8, Technical Note pp337-340.

REFERENCES (cont.)

- Gora, E. (1998) Wastes in the Environment, Contaminated and Derelict Land "Green 2, Bolton, UK", pp 497-500.
- Gotoh, S., (1987) The Japanese Concept and Standards for Waste Landfilling, Proceedings Sardinia '87.
- Grimski (1988) Dichtungssysteme fur Deponien - die bundesdeutschen Ansatze im internationalen Vergleich. In: Fachtagung Die sichere Deponie, pp 209-233.
- Gronow, J., Harris, B. (February 1996) LANDSIM: A regulatory tool for the assessment of landfill site design, Wastes Management, pp. 30-32.
- Halse, Y., Koerner, R.M., and Lord, A.E. Jr. (1989) Laboratory Evaluation of Stress Cracking in HDPE Geomembrane Seams, Proc. GRI Seminar on Aging and Durability of Geosynthetics, Elsevier Publishing Co., London, England, pp. 177-194.
- Harper, S.R., Poland, F.G. (November 1998) Landfills: Lessening Environmental Impacts, Civil Engineering, pp 66-69.
- Hoekstra, S.E. (1995) Final Capping and Finishing of a Landfill in Limburg, The Netherlands, Waste Disposal by Landfill "Green '93, Bolton, UK" - 1993, pp 643-648.
- Holzlohner, U., August, H., Meggyes, T., Brune, M. (1995) English translation by David M Anderson, T Meggyes, "Landfill Liner Systems" - A State of the Art Report: Penshaw Press, pp.
- Jasinski, R. (March 1985) Flexible Membrane Liners: Specification Considerations, Waste Age, pp65-70.
- Jessburger, H.L. (April 1994) Geotechnical Aspects of Landfill Design And Construction, Proceedings of the Institution of Civil Engineers, Geotechnical Engineering, 107 Parts 1-3, pp 99-122.
- Kenney, T.C., van Veen, W.A., Swallow, M.A., Sungaila, M.A. (1992) Hydraulic Conductivity of Compacted Bentonite-Sand Mixtures, Canadian Geotechnical Journal 29, pp 364-374.
- Khire, M.V., Benson, C.H., Bosscher, P.J. (August 1997) Water Balance Modelling of Earthen Final Covers - , Journal of Geotechnical and Geoenvironmental Engineering, Vol.123, No.8, pp 744-754.

REFERENCES (cont.)

- King, T. (March 1997) Recycling Is The Best Way To Deal With Rubbish, Daily Telegraph.
- Koerner, G.R., (1993) Performance Evaluation Of Geotextile Filters Used In Leachate Collection Systems Of Solid Waste Landfills, Geosynthetics Research Institute, Drexel University.
- Koerner, R., Daniel, D. (1994) A suggested methodology for Assessing Technical Equivalency of GCLs to CCLs, GRI-7 Conference on "Geosynthetic Liner Systems", IFAI Publications, St. Paul, MN, USA.
- Koerner, R.M. (1986) Use of Flexible Membrane Liners for Industrial and Hazardous Waste Disposal, ASTM Special Publication 933PUG Philadelphia USA. pp195-207.
- Koerner, R.M. (March 2000) Geosynthetics in Waste Containment Systems Seminar, Wetherby, UK.
- Koerner, R.M., Daniel, D.E. (May 1992) Better Cover Ups - Civil Engineering, pp 55-57.
- Koerner,G.R., Koerner, R.M., Martin, J.P. (October 1994) Design of Landfill Leachate Collection Filters, Journal of Geotechnical Engineering, Vol.120, No.10, pp 1792-1803.
- LaGatta, M.D., Boardman, B.T., Cooley, B.H., Daniel, D.E. (May1997) Geosynthetic Clay Liners Subjected to Differential Settlement, Journal of Geotechnical and Geoenvironmental Engineering, Vol.123, No.5, pp 402-410.
- Landreth, R.E. (1990) Landfill Containment System Regulations, ASCE Geotechnical Special Publication No 26, pp 1-13.
- Lo, I.M.C, Mak, R.K.M., Lee, S.C.H. (January 1997) Modified Clays for Waste Containment and Pollutant Attenuation, Journal of Environmental Engineering, Vol.123, No.1, pp 0025-0032.
- Local Authority Waste & Environment, (August 1997) Landfilling Tax Funds Recycled Into Composting Research and Development, Vol. 5, Issue 8, pp 9.
- Local Authority Waste & Environment,(August 1997) High-tech. Incineration is the Key to Winning Public Image Battle, Vol. 5, Issue 8, pp 18.

REFERENCES (cont.)

- Lustiger, A., Rosenberg, J. (Undated) Predicting the Service Life of Polyethylene in Engineering Applications,AT&T Laboratories.
- Materials Recycling Weekly, (5 September 1997).
- Mazetti, G., Saetti, G., Tirapani, M., (1991) Reclassification of a Sanitary Landfill. A Case Study at Palastreto, Proceedings Sardinia '91, pp 1355-1364.
- McCarthy, Michael, Environment Correspondent, (24 January 2000) Network of Massive Incinerators planned for UK, The Independent.
- McKendry, P. J. (February, 1993), Geomembranes: Facts & Fallacies, Wastes Management, pp31-32.
- McKendry, P.J. (1995) Risk Assessment of Engineered Containment Landfill Designs, Waste Disposal by Landfill "Green '93, Bolton, UK", pp 35-46.
- Minor, S.D., Jacobs T.L. (Sept/Oct 1994) Optimal Land Allocation For Solid And Hazardous Waste Landfill Sites, Journal of Environmental Engineering, Vol.120, No.5, pp 1095-1108.
- Mitchell, J.K. (11-15 July, 1994) Physical Barriers for Waste Containment, Proceedings of the First International Congress on Environmental Geotechnics, Edmonton, Canada.
- Mitchell, J.K., Mitchell, R.A. (19-21 Novembre 1991) Stability of Landfills: - Conferenze di Geotecnia di Torino, XVCICLO.
- National Recycling Directory (1995-1996), Waste Watch/LARAC.
- Needham, A. (1991) Clay Liners: The Answer Lies In The Clay, WasteExpo '91, pp 11-13.
- Nordquist, J.E. (1990) Comparison of Laboratory and Field Measured Hydraulic Conductivities of Soil Liners, Chen-Northern Inc., Annual Symposium on Engineering Geology and Geotechnical Engineering.
- North West Waste Disposal Officers, Landfill Liners Sub-Group (October 1988) Guidelines on the Use of Landfill Liners, published by Lancashire Waste Disposal Authority.
- North, R.D. (1 November 1994) Rubbish: The Rotten Truth, The Independent, pp 24.

REFERENCES (cont.)

- Outerbridge, T. (May/June 1994) The Big Backyard - Composting Strategies in New York City, The Ecologist, Vol.24, No.3, pp 106-109.
- Oweis, I.S., Dakas, G., Marturano, T.S., Wierer, R. (October 1994) Soil Cover Success, Civil Engineering, pp 58-59.
- Panno, S.V., Herzog, B.L., Cartwright, K., Rehfeldt, K.R., Krapac, I.G., Hensel, B.R. (November-December 1991) Field Scale Investigation of Infiltration into a Compacted Soil Liner: Groundwater, Vol.29, No6, pp914-921.
- Petrov, R.J., Rowe, R.K.Quigley, R.M. (August1997) Selected Factors Influencing GCL Hydraulic Conductivity, Journal of Geotechnical and Geoenvironmental Engineering, Vol.123, No8.
- Pita, F.W., Reeser, D.M., Dransfield, J.S. (1986) Groundwater Protection Using Natural Soil Liner in Landfill Leachate Collection: Case Histories, Environmental Conference Proceedings of the Technical Association of Pulp and Paper Industry, pp167-172,
- Porbaha, A., Goodings, D.J. (1996) Centrifuge Modelling of Geotextile Reinforced Steep Clay Slopes, Canadian Geotechnical Journal 33, pp 696-704.
- Potter, H.A.B., Yong, R.N. (1995) Waste Disposal by Landfill in Britain: Problems, Solutions and the Way Forward, Waste Disposal by Landfill "Green '93, Bolton, UK", pp 167-174.
- Rachel's Hazardous Waste News (18/4/1989) No. 125.
- Rachel's Hazardous Waste News (21/2/1989) No. 117.
- Rachel's Hazardous Waste News (23/1/1991) No. 217.
- Rhew, R.D., Barlaz, M.A. (July 1995) Effect of Lime Stabilised Sludge as Landfill Daily Cover on Refuse Decomposition, Journal of Environmental Engineering, Vol.121, No.7, pp 499-506.
- Rios, N., Gealt, M.A. (Undated) Biological Growth in Landfill Leachate Collection Systems, Department of Bioscience and Biotechnology, Drexel University.
- Robinson, N. (1995) An Overview of the Technology of Waste Disposal by Landfill in the United Kingdom, Waste Disposal by Landfill "Green '93, Bolton, UK", pp 11-18.
- Rogers, D. (February 1993) Bentonite Basal Liners, Wastes Management, pp34.

REFERENCES (cont.)

- Sanchez- Alciturri, J.M., Palma, J., Sagaseta, C., Canizal, J (1995) Three Years Deformation Monitoring at Meruelo Landfill,Spain, Waste Disposal by Landfill "Green '93, Bolton, UK", pp 357-364.
- Seymour, K.J. & Street, A. (1995) Landfill Engineering - UK Practice and Guidance in a European Context:, Waste Disposal by Landfill "Green '93, Bolton, UK", pp 189-194.
- Smith, M.E. (January 1997) Putting On Your Safety Cap, Civil Engineering, pp 52-54.
- Sophocleous, M., Stadnyk, N.G., Stotts, M. (December 1996) Modelling Impact of Small Kansas Landfills on Underlying Aquifers, Journal of Environmental Engineering, Vol 122, No.12, pp1067-1077.
- Stark, T.D., Williamson, T.A., Eid, H.T. (March, 1996) Journal of Geotechnical Engineering, Vol. 122, No. 3, pp 197-203.
- Statham, I., Treharne, G. (1998) The Combined Use of Inward Hydraulic Gradient and In-Ground Barriers for Groundwater Pollution Control at Waste Management Sites. GREEN 2, Contaminated and Derelict Land, Krakow, Poland. Thomas Telford, London, pp368-375.
- Steffen, H., (1992) Die Eignung von Asphalt zur Deponieabdichtung. In: Abdichtung von Deonien und Altlasten, Grundkursus, pp 183-201.
- Stief, K., (1986) Das Multibarrierenkonzept als Grundlage von Planung, Bau, Betrieb und Nachsorge von Deponien. Mull und Abfall 1, pp 15-20.
- Street, A., Davies, K., McKendry, P., (May 1996) Guidance On Good Practice For Landfill Engineering, Rust Environmental Report for UK DoE.
- Sutter II, G.W., Luxmore, R.J., Smithh, E.D. (1993) Compacted Soil Barriers At Abandoned Landfill Site Are Likely To Fail In The Long Term, Journal of Environmental Quality 22, pp 217-226.
- Tchobanoglous, G., Theisen, H., Vigil, S.A. (1993) Integrated Solid Waste Management, McGraw-Hill International Editions.
- The Waste Manager (December 1997).

REFERENCES (cont.)

- Thomas, R.W., Bartz, A.K., Verschoor, K.L. (Undated) Evaluation of Oxidative Stability of High Density Polyethylene Geomembranes by Isothermal and Dynamic Differential Scanning, Environmental Sciences Division, Texas Research International Inc..
- Townsend, T.G. Miller,W.L., Earle, J.F.K. (June1995) Leachate - Recycle Infiltration Ponds, Journal of Environmental Engineering, Vol.121, No.6, pp 465-471.
- Trauger, R. (CETCO) (1996) Designing With Geosynthetic Clay Liners: Proceedings of the International Seminar and Technomeet on Environmental Geotechnology with Geosynthetics, pp233-246.
- Uehling, M. (28 October,1993) Keeping Rubbish Rotten to the Core, New Scientist.
- USEPA (1987a) Minimum Technology Guidance on Double Liner Systems for Landfills and Surface Impoundments - Design, Construction and Operaton. EPA/530-SW-85-014.
- USEPA (1987b) Background Document on Bottom Liner Performance in Double-Lined Landfills and Surface Impoundments. EPA 530/SW-87-013.
- USEPA (1988a) Lining of Waste and Other Impoundment Facilities (by Matrecon Inc. Alameda, CA). EPA/600/2-88/052
- USEPA (1988b) Guide to Technical Resources for the Design of Land Disposal Facilities. In: EPA Guidance Document: Final Covers on Hazardous Waste Landfills and Surface Impoundments. EPA/530-SW-88-047.
- USEPA (1989a) Technical Guidance Document: Final Covers on Hazardous Waste Landfills and Surface Impoundments. EPA/530-SW-89-047.
- USEPA (1989b) Geosynthetic Leachate Collection Systems (by R.E. Landreth). EPA/600/D-91/019.
- USEPA (1991) Design & Construction of RCRA/CERCLA Final Covers (by Eastern Research Group, Inc., Arlington, MA). Seminar Publication, EPA/625/4-91/025.
- Wallis, M.K. (1995) Reassessing Methane from UK Landfills, Waste Disposal by Landfill "Green '93, Bolton, UK", pp 291-296.

REFERENCES (cont.)

- Walton, J., Rahman, M., Casey, D., Picornell, M., Johnson, M. (June 1997) Leakage Through Flaws in Geomembrane Liners, Journal of Geotechnical and Geoenvironmental Engineering, Vol.123, No.6, pp 534-539.
- Warmer Bulletin 42, (August 1994).
- Waste Management - Changing Our Ways (1998), Department of the Environment and Local Government, Eire.
- Wing, N.R., Gee, G.W. (October 1994) Quest For The Perfect Cap, Civil Engineering, pp 38-41.
- WMP No. 04 (1994) - Waste Management Licensing, HMSO, UK.
- WMP No. 26A (1993) - Landfill Completion, HMSO, UK.
- WMP No. 26B (1995) - Landfill Design, Construction and Operational Practice, HMSO, UK.
- WMP No. 26D (2000) - Landfill Monitoring, HMSO, UK.
- WMP No. 26E (1996) - Landfill Restoration and Post Closure Management, HMSO, UK.
- WMP No. 27 (1989) - The Control of Landfill Gas, HMSO. UK.
- Woyshner, R.M., Yanful, K.E. (1995) Modelling and Field Measurements of Water Percolation Through an Experimental Soil Cover on Mine Tailings, Canadian Geotechnical Journal 32, pp 601-609.
- Yanful, E.K., Shikatani, K.S., Quirt, D.H. (1995) Hydraulic Conductivity of Natural Soils Permeated with Acid Mine Drainage, Canadian Geotechnical Journal 32, pp 624-646.
- Zimmie T.F., Moo-Young H., LaPlante, K. (1995) The Use of Waste Paper Sludge for Landfill Cover Material, Waste Disposal by Landfill "Green '93, Bolton, UK", pp 487-496.